JPRS 70602

7 February 1978

USSR

TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY
PHYSICAL SCIENCES AND TECHNOLOGY

No. 28

U. S. JOINT PUBLICATIONS RESEARCH SERVICE

116

NOTE

JPRS publications contain information primarily from foreign newspapers, periodicals and books, but also from news agency transmissions and broadcasts. Materials from foreign-language sources are translated; those from English-language sources are transcribed or reprinted, with the original phrasing and other characteristics retained.

Headlines, editorial reports, and material enclosed in brackets [] are supplied by JPRS. Processing indicators such as [Text] or [Excerpt] in the first line of each item, or following the last line of a brief, indicate how the original information was processed. Where no processing indicator is given, the information was summarized or extracted.

Unfamiliar names rendered phonetically or transliterated are enclosed in parentheses. Words or names preceded by a question mark and enclosed in parentheses were not clear in the original but have been supplied as appropriate in context. Other unattribute parenthetical notes within the body of an item originate with the source. Times within items are as given by source.

The contents of this publication in no way represent the policies, views or attitudes of the U.S. Government.

PROCUREMENT OF PUBLICATIONS

JPRS publications may be ordered from the National Technical Information Service (NTIS), Springfield, Virginia 22151. In ordering, it is recommended that the JPRS number, title, date and author, if applicable, of publication be cited.

Current JPRS publications are announced in Government Reports Announcements issued semimonthly by the NTIS, and are listed in the Monthly Catalog of U.S. Government Publications issued by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Indexes to this report (by keyword, author, personal names, title and series) are available through Bell & Howell, Old Mansfield Road, Wooster, Ohio, 44691.

Correspondence pertaining to matters other than procurement may be addressed to Joint Publications Research Service, 1000 North Glebe Road, Arlington, Virginia 22201.

BIBLIOGRAPHIC DATA SHEET	1. Report No. JPRS 70602	2.	3. Recipient's Accession No.

4. Title and Subtitle TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY - PHYSICAL SCIENCES AND TECHNOLOGY No. 28	5. Report Date 7 February 1978
	6.
7. Author(s)	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Joint Publications Research Service 1000 North Glebe Road Arlington, Virginia 22201	10. Project/Task/Work Unit No.
	11. Contract/Grant No.
12. Sponsoring Organization Name and Address As above	13. Type of Report & Period Covered
	14.

15. Supplementary Notes

16. Abstracts

The report contains information on aeronautics; astronomy and astrophysics; atmospheric sciences; chemistry; earth sciences and oceanography; electronics and electrical engineering; energy conversion; materials; mathematical sciences; cybernetics, computers; mechanical, industrial, civil, and marine engineering; methods and equipment; missile technology; navigation, communications, detection, and countermeasures, nuclear science and technology; ordnance; physics; propulsion and fuels; space technology; and scientists and scientific organization in the physical sciences.

17. Key Words and Document Analysis. 17a. Descriptors

USSR	Electronics	Missile Technology
Aeronautics	Electrical Engineering	Navigation and Communications
Astronomy	Energy Conversion	Detection and Countermeasures
Astrophysics	Materials	Nuclear Science and Technology
Atmospheric Sciences	Mathematics	Ordnance
Chemistry	Mechanical Engineering	Physics
Computers	Civil Engineering	Propulsion and Fuels
Cybernetics	Industrial Engineering	Space Technology
Earth Sciences	Marine Engineering	
Oceanography	Methods	
	Equipment	

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group 01,03,04,07,08,09,10,11,12,13,14,16,17,18,19,20,21,22

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited Availability Sold by NTIS Springfield, Virginia 22151	UNCLASSIFIED	116
	20. Security Class (This Page) UNCLASSIFIED	22. Price PC A06

FORM NTIS-35 (REV. 3-72)

THIS FORM MAY BE REPRODUCED

USCOMM-DC 14952-P72

JPRS 70602

7 February 1978

TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY
PHYSICAL SCIENCES AND TECHNOLOGY

No. 28

CONTENTS PAGE

CONTENTS (Continued)

Page

CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

CENTRALIZED TECHNICAL MAINTENANCE OF COMPUTERS

Kiev PRAVDA UKRAINY in Russian 7 Sep 77 p 2

[Article by M. Trofimchuk, winner of the Lenin Prize, Director of the "Zapad EVM Kompleks" production association: "How Are You Working, EVM?"]

[Text] Today under conditions of the scientific-technical revolution it is practically impossible to imagine further development of modern socialist production without the broad application of electronic computer technology. That is why in the decisions of the 25th party congress a firm goal of increasing its output by 1.8 times was set.

In recent years in the Soviet Union and in the CEMA nations, a vigorous industry producing a Unified System of electronic computers (EVM) has been established. In our country alone they are being manufactured in more than eighty plants and associations in which several hundred thousand workers and specialists labor.

Our government and the CEMA nations expend a tremendous amount of resources in the development, delivery and operation of EVM. And in order that they not only pay for themselves, but also yield a profit, it is necessary to use this technology as effectively as possible--and with minimum expenditure--ensure its high operational readiness.

Unfortunately, at the present time many EVM and calculator centers in plants, associations and even in branches are not working at full capacity and are not being provided with highly skilled specialists, which significantly reduces the effectiveness of the use of this technology. In the future, even with a sharp expansion of the EVM inventory, the number of maintenance personnel must not increase. A high machine operating efficiency must be effected only through centralized and integrated machine maintenance, by the formation of community-use computer centers and by the future centralization of material and human resources within the scope of the specialized organizations.

Within the territory of the Ukraine and Moldavia there are hundreds of third generation EVM, the technical maintenance of which occupies more than five

thousand workers. Therefore the question of integrated centralized machine maintenance is now already being posed. In comparison with independent maintenance, as shown by preliminary calculations, it yields a reduction of existing engineering and technical personnel by 30-40 percent.

At the beginning of last year the all-union association, Soyuz EVM Kompleks, was formed. It was funded by its users to provide for procurement, assembly, adjustment and putting into operation of those complexes of technical devices of the EVM Unified System which are necessary to the users. This includes also other types of specialized and optional equipment, as well as putting appropriate operating systems and general purpose applications programs into service; conducting warranty, post-warranty and routine servicing; repair of the computer equipment; and producing operational systems and general purpose applications programs, which are constantly being improved, as well as appropriate operational, technical and training documentation. Lying within the range of the association's responsibilities are also planning the layout for the EVM equipment, its standard internal installation design, and the training and retraining of operations personnel.

To perform these tasks in the areas of the Ukraine and Moldavia, the Zapad EVM Kompleks, with its center in Kiev, has been established within the staff of the all-union Soyuz EVM Kompleks. However, we presently have only 25 percent of the entire EVM inventory located in this area for centralized technical servicing. Meanwhile, the benefits from such maintenance have been obvious. If it were to include all the computer equipment just in the areas of the Ukraine and Moldavia, it would be possible to free some two thousand people. Furthermore, comprehensive, centralized maintenance allows for a significant reduction of expenditures for spare parts, which in turn allows the plants and manufacturers to significantly raise their output of additional units.

By our calculations, as applied to the Ukranian-Moldavian region, this saves 50 million rubles.

Under comprehensive centralized maintenance, the time required to put technical EVM facilities into operation is noticeably reduced. Until recent times, enterprises and organizations frequently received EVM while having available neither trained operations personnel nor suitable accommodations. Expensive equipment lay in unsuitable warehouses. It's not difficult to estimate what it cost the government to store the ES-1020 machine No 447 from the Minsk Plant for 17 months at the "Svema" production association in Sumy. The same type of machine was idle for almost a year in the Donetsk Polytechnical Institute; an ES-1030 didn't operate for 15 months at the Mathematics Institute of the AN MSSR in Kishinev.

Now in our association a planning-design-technological bureau has been formed. It will plan the disposition of technical EVM facilities and also their standard internal installation design.

It is common knowledge that EVM operating efficiency increases if expenditures for putting complete operating systems and general purpose applications programs into service are reduced. To accomplish this in a production association, an office is formed which supplements basic programming services. The absence of such an office in enterprises having EVM's forced them to maintain a large number of highly skilled mathematics specialists, and spend much time and resources on their retraining, on the acquisition of necessary mathematical support and on the organization of data processing maintenance.

Operational experience of the organizations already having their computers on centralized technical maintenance shows that the daily period in which each EVM is idle because of a technical malfunction has already been reduced by an average of 1.5 hours. And that means a standard yearly savings of several million rubles.

In accordance with the long-range plan for our association's development through the end of the five-year plan, it was decided to create a branching network of technical maintenance points, laboratories and regional centers so that the ES EVM pool located in the Ukranian-Moldavian zone would be encompassed by comprehensive centralized maintenance. However, today the "Zapad EVM Kompleks" is still not in a position to increase its volume of centralized comprehensive maintenance work in order to successfully solve the important national economic task of efficient utilization of the EVM inventory. Despite the fact that the Council of Ministers of the USSR obligated all ministries and departments to incorporate their facilities in centralized technical maintenance in 1977, at the present time not all enterprises and organizations are approaching this question carefully by the government's method. The association is experiencing great difficulties with production areas and transportation facilities in expeditiously supplying specialists to the users. We place great hope on the help from the Party and council organs of Kiev, Khar'kov, Kishinev, L'vov, Odessa and Simferopol' where association subdivisions are already organized, and also from other cities of the republics where such subdivisions will be created as required.

Electronic computer technology must operate with maximum efficiency. And to achieve that is a task of great governmental importance.

9082
CSO: 1870

CYBERNETICS, COMPUTERS AND AUTOMATION TECHNOLOGY

COMPUTER UTILIZATION IN AZERBAYDZHAN SSR

Baku VYSHKA in Russian 23 Jul 77 p 2

[Article by Dzh. Allakhverdiyev, corresponding member of Azerbaydzhan SSR Academy of Sciences, director of the Institute of Cybernetics: "Computers To Be Used Efficiently"]

[Text] In the resolutions of the 25th CPSU Congress serious quotas were indicated for increasing the quality level of control on a Statewide scale. One of the most important of these is creation of an all-State automated system for gathering and processing data. This will make it possible to control the national economy more efficiently. The foremost importance of this goal is indicated also by the fact that practically all ministries and departments have been enlisted for the job of creating ASU's [automated control systems] of different levels. Only an overall solution to questions relating to setting up computer centers and utilizing computers within the framework of ASU's in all sectors of the national economy will make it possible to gain the immense savings anticipated.

In the republic a network of computer centers (VTs's) has been created, development is under way, and ASU's of various levels are already functioning; utilization of computers in industry and other spheres of the national economy has expanded. The Interdepartmental Council on Questions Relating to Controlling the National Economy is directing and coordinating the activities of numerous organizations involved in putting computers into operation.

The Azerbaydzhan SSR Academy of Sciences Institute of Cybernetics, as the head organization for development of the "RASU-Azerbaydzhan" [Azerbaydzhan Republic Automated Control System], has established close business contacts with computer centers and ASU subdivisions of ministries and departments of the republic. In this article the writer would like to give some ideas relating to questions of increasing the efficiency of utilization of computer technology.

Today the republic has at its disposal a considerable inventory of computers. This consists mainly of medium- and low-capacity machines which are utilized in the national economy. Looking at a cross section divided into sectors,

the greatest number of computers is used in industry (32.3 percent), in higher educational institutions (28.2 percent), and in scientific institutions (11.3 percent).

Mention should be made of the great organizational work of a number of ministries and departments in creating, putting into operation, and setting up groups of computer centers and their ASU subdivisions, and of the successes achieved in the scientific and applied areas. In the republic the first phases of seven ASU's have been put into operation, which cover 146 problems, and about 600 problems have been prepared for introduction, thus creating a sufficiently large surplus for the immediate future.

The most substantial results have been achieved at the republic's TsSU [control systems center] computer center. Now every month here more than 20 labor intensive kinds of reports are being computer processed, reports on supply of materials and equipment, labor, capital construction, budgetary surveys of the republic's population, etc., which has been conducive to considerable reduction of the time required for preparing statistical data and to increased efficiency of this process.

Deserving a favorable reception is the set of problems on controlling supplies of metal, with its actual annual savings of 296,000 rubles, developed and put into everyday use by the team at the VTs of the republic's Glavsnab [Main Supply Administration].

Outstanding successes have been achieved by the team of the Azglavenergo Association's computer center. Just three of the series of optimization problems introduced for regulating operating modes of power systems have provided an annual savings of material expenditures for producing electrical energy to the tune of 400,000 rubles. Mention should also be made of the large job of expanding the subjects of problems analyzed by centers of the Azneft' Association, of Kaspar, of NBNZ [expansion unknown] imeni Vladimir Il'yich, and others.

Specific work has been done by the computer centers of VUZ's on developing, introducing, and using a series of intradepartmental problems on controlling admission and the educational process of students, which are part of the "Upper Level Education ASU" complex.

An important contribution to hastening scientific exploration has been made by sets of problems adopted by institutes of the Azerbaydzhan SSR Academy of Sciences in the field of economics, chemical technology, petrochemistry, physics, geology, and others. Here problems are beginning to be introduced which are part of the "Science ASU" complex.

But for the republic as a whole these successes look more than modest when charted against modern needs. What causes alarm above all is insufficient utilization of the current computer inventory: The mean 24-hour utilization figure per machine in 1976 in the republic was 7.5 hours, while this factor reached 13 hours for the country.

Whereas, for example, the average utilization factor at the VTs's of the Azneft' Association, Kaspar, and the Azerbaydzhan Railway was 18 to 20.5 hours per 24-hour period for the "Minsk-32," and 13.2 to 19.5 hours for the YeS-1020, at the VTs of the republic's Minavtotrans [Ministry of Motor Vehicle Transportation] the "Minsk-32" was utilized for 15.1 hours, and the YeS-1020 for only 2.6; at the VTs of Minpromstroy [Ministry of Industrial Construction] the "Minsk-32" and YeS-1020 were utilized for only 4.1 and 0.6 hours, respectively.

Furthermore, far from isolated are cases of computer idle time for technical reasons and because of a lack of problems ready for solution. And this equipment is expensive and each hour of idle time brings considerable losses.

At the same time, to look even deeper, it appears that computers are utilized with insufficient efficiency even from the viewpoint of machine time. A great proportion of it is spent not on solving problems, but just on debugging them. This, although indirectly, testifies to the insufficient skill of programmers and operators.

Doubt is also created with regard to accuracy in selection of many problems recommended for adoption. Their content not infrequently does not yield important results.

What are the causes which have led to such low computer efficiency? One is underestimation of the importance of preliminary analysis and intense study of processes for whose control utilization of the computer is suggested. Therefore, in some ministries and departments adoption and implementation of ASU problem solutions has been excessively delayed, and their selection is at times libertarian.

Attention should be paid to the fact that frequently first in line to be chosen for solution are problems of recordkeeping and scheduling, and these are mainly oriented toward traditional document flow and developed methods of storing and accumulating data. The operations of a number of VTs's are involved just with solving urgent problems. Meanwhile slow to be mastered are the most important problems of analyzing economic processes and financial decisions making it possible to optimize and increase production efficiency substantially.

Numbered among the reasons hampering an increase in computer utilization must also be the fact that managers and responsible coworkers of ministries and departments do not always offer the proper assistance and help to teams at computer centers in obtaining and forming raw data for solving economic problems. In addition, data for solving ASU problems is not provided on a timely basis, and nobody is legally responsible for this.

Mention must also be made of the acute shortage in the republic of troubleshooters and operators to service computers, and of highly skilled programmers. At the same time the republic's VUZ's are continuing to put out an insufficient

number of specialists in systems analysis, programming, and the use of mathematical economic methods in various sectors of the national economy. And the level of training of specialists is even such that graduates are frequently not in a position to begin performing their duties without prolonged extra training on the job. As a result of this, the skill of specialists hired to develop and introduce ASU's at the Aztrub Plant imeni Lenin, the IVTs [computer and information center] of Minpromstroy and of Minsvyaz' [Ministry of Communications], and several other places does not match the level of the problems posed. Because of a shortage of skilled personnel many employment positions have not been filled at the IVTs of the Azplodoovoshchprom Association, Mintorg [Ministry of Trade], and others.

One of the important problems of today in the republic is poor dissemination of advanced know-how in developing, introducing, and using computers, as well as lack of a system of increasing the skills of developers, operators, and users. It is therefore advisable to arrange as soon as possible for systematic retraining of all personnel involved with computers within the scope of ministries and departments at all levels, for the purpose of their mastering new methods in application of computer technology and systems engineering. Improvements are also necessary in the system of wages and incentives for specialists at computer centers.

Substantial improvement is also necessary in the work of the republic's association of users of United Computer System machines. Here it is necessary to create with a tight deadline a qualified group for approving, accepting, and setting up a centralized storage system for algorithms and programs and planning solutions developed and to be used in the republic.

Creation of the "RASU-Azerbaydzhan" makes it necessary even today, without delay, to start developing branch ASU's in such important components of the republic control system as the ministries of finance, light industry, agriculture, and rural construction, offices of USSR Gosbank, and a whole series of others.

The republic's national economy is developing at a rapid rate in the 10th Five-Year Plan. Its scale, and along with this questions relating to controlling it are becoming more complicated, extensive, and vast with each passing day. At the November (1976) Plenum of the Central Committee of the Azerbaydzhan Communist Party, which discussed problems of the republic's party organization resulting from the decisions of the October (1976) Plenum of the Central Committee of CPSU, it was emphasized that extensive introduction of automated control systems is one of the most important resources for increasing efficiency further. It is necessary to apply all our efforts to solving this problem.

8831
CSO: 1870

CONSTRUCTION PROGRESS AT KIEV COMPUTER PLANT

Moscow SOTSIALISTICHESKAYA INDUSTRIYA in Russian 11 May 77 p 1

[Article by Zh. Tkachenko in the column "Starts--Under Control": "An Explanation is Needed"]

[Text] Two peculiarities mark the large operation in progress at the Kiev Computer and Electronic Control Equipment Plant. In the first place, the accumulation of machinery is being accomplished by rearranging the operating parts of the production equipment. In the second place, the volume of construction work is comparatively small in terms of significant end product. There is also a third: not one of these installations can operate without the other. So, for example, the printed-circuit board assembly shop, one of the main facilities, cannot be operated without stations for neutralizing drainage water. And both of these together cannot function at all without a step-down substation.

"The circumstances are aggravated," says OKS [Capital Construction Department] Chief Engineer A.A. Royter, "by the fact that substations are essential to the undertaking right at this point. Our situation is almost an emergency. Not once have we received an explicit directive from the power engineers. Without one it is impossible even to talk about starting the new complex."

But the situation is most troublesome precisely at this point in starting the complex. Even if equipment assembly is soon started in the printed circuit board shop, which is being set up at a good rate, and even if work is going according to schedule in the construction of the neutralization station, where an SMU-14 is doing the work for the Kievpromstroiy Plant and a start in the fourth quarter of the current year is not in doubt, not only is the substation not being built at this time, but it is not even known who will build it.

This situation, a case of bureaucratism, is on the whole unprecedented and something which should be examined in greater detail.

In order to put the complex to work a step-down substation is needed. One was included in the contract work plan for the plant this year, and money in

the amount of 662,000 rubles was allocated. The planning and budget documents are completely prepared and the equipment has been sent for. But the general contractor, Trust No, 1, has refused to construct the facility, citing a direct order from the Kievpromstroy Plant. And that plant in its turn refers to the UkSSR Minpromstroy [Ministry of Industrial Construction]. The republic's ministry is guided by an interpretation of the USSR Gosplan and USSR Gosstroy from July 4, 1973 in No. 951-11, holding that the USSR Minenergo organizations must set up the substation. But the power engineers are pushing their own interpretation and are convinced that the republic Minpromstroy organizations should build the substations.

The circle is complete. There is no third organization which might take the responsibility for building the substation.

It is very curious what sorts of quotations are made from one and the same document. For the sake of the truth, it must be said that it does give grounds for various meanings.

The interpretation signed by Deputy Chairman of USSR Gosplan V. Isayev and Deputy Chairman of USSR Gosstroy M. Chentemirov says: the union Gosplan and the union Gosstroy consider that the construction of step-down substations at production complexes must, as a rule, be entrusted to the construction ministry organizations who are constructing these complexes. USSR Minenergo must perform the assembly work on subcontracting claims at these substations. It is as if everything were quite clear-cut, but there is still one point: in the different instances given where the general construction organizations of USSR Minenergo are involved in building a large complex, all construction work on the step-down substations contained in the structure of the complex may be assigned to USSR Minenergo for general contracting.

And that is what happens: one bureaucratic organization quotes one part of the interpretation and the other one another part, whichever is more advantageous.

As for the Kiev plant, that is just a very specific case, since crane No 80 of the L'vov Yugzapelyektrosyet'stroy Trust, located in the area where the complex is being built, is ready and could erect the substation. But without instructions from its management, it cannot do a thing.

Thus, the most important installation of the complex which has been started is not yet under construction. Who will take on the responsibility of explaining the "interpretation" for the practical good?

8945
CSO: 1870

ORGANIZATIONAL SNAGS IN WORK TO INTRODUCE NEW ASU'S

Moscow SOVETSKAYA ROSSIYA in Russian 12 July 77 p 2

[Article by doctor of technical sciences I. Bobko: "The Examination of the 'Sigma'"]

> [Text] The Greek letter Sigma, which means the "sum of sums," the sum of everything, is the symbol of the Siberian Department of the Academy of Sciences USSR. Sigma is also the name that has been given to an automated production control system developed by Novosibirsk scientists, which performs a broad range of tasks. This system is an innovation in the science of production control. Its introduction requires precise coordination of the efforts of scientists at academy and sectorial scientific research institutes, specialists of sectorial design bureaus, and production people.

The interdepartmental state commission accepted the detail design of the Sigma automated control system and recommended it to those enterprises of the machine building and instrument making sectors which are already setting up ASU's [automated control systems] based on third-generation computers.

It is noteworthy that the number of experts who participated in acceptance of the design was several times larger than the number of members on the commission itself. The design of the new automated system aroused great interest among specialists. The reason for this is that the Sigma system, like its ASU predecessor the Barnaul, differs significantly from conventional systems in its structure, features of software, and some principles of control; in addition, and this is very important, it uses different forms and methods for introduction at specific enterprises.

Considerable experience has already been accumulated in development and operation of the Barnaul ASU; proper documents have been turned over to 150 enterprises and many of them have incorporated the system. It has been used for about seven years at the Barnaul radio plant and the Altay Plant for Tractor Electrical Equipment and shown great efficiency; it

has helped raise labor productivity, reduce losses, and improve production rhythm.

The accumulated experience enabled the Siberian Department of the Academy of Sciences and the Institute of Cybernetics of the Academy of Sciences Ukrainian SSR to begin work confidently on the assignment of the State Committee for Science and Technology of the USSR Council of Ministers: design an automated control system based on third-generation computers. The collective of developers set as its task broadening the functions of the automated control system while keeping costs to a minimum. For example, the Institute of Economics and the Organization of Industrial Production of the Siberian Department of the Academy of Sciences USSR and the Scientific Research Institute of Automated Systems for Planning and Control designed a complex to prepare for the production of new articles, something that is very essential to a modern enterprise.

The Sigma ASU can be spread to many enterprises without substantial expenditures. Right now one base variation is being used at three enterprises which differ by nature and volume of production as well as sectorial affiliation. The structure of the system allows an enterprise to first test it in one shop and, after the successful examination, to spread it to other areas.

Relying on experience with the earlier ASU, the developers applied new working principles in the Sigma. Specifically, they envisioned a human "dialogue" mode with the machine.

The system opens up opportunities to resolve new problems of scientific-technical progress and this work has already been turned over to the developers. For example, it is planned to build a complex for automated control of production processes.

While introducing the Sigma the developers are improving what they call its adaptability, the ability to automatically adjust to the specific characteristics of different enterprises. This will help sharply cut costs for setting up the automated control system.

The economic aspect of this work is crucial. Unfortunately, this is not always taken into account in all places. Many questions related to stimulation of enterprises which are energetically introducing ASU's remain to be solved. As a result, we find a paradoxical situation. If the automated system works out well, the enterprise will naturally change gradually to more precisely calculated standards and technical-economic indices. But then the plant will find itself at a disadvantage compared to other plants which enjoy what are called privileged conditions. The pioneers in a new area take the role of leaders in the sector. We realize that they take on increased expenditures related to introduction of the system. They are blazing the trail for many other collectives. This kind of innovation and willingness to take a justified production risk must be encouraged. In practice, however, it frequently turns out just the opposite.

The Barnaul Radio Plant bore the costs of introducing the Barnaul ASU and found itself in a difficult situation; it did not receive the support of its ministry right away. How much easier it was at this time for other enterprises which were receiving materials according to norms calculated, as production people say, with a hedge on the high side, something that the automated system would not permit.

Ultimately, it is true, when the radio plant had markedly improved its production efficiency, the attitude of these enterprises did change. They finally incorporated the Barnaul system, and now they are introducing the Sigma system there. But one gets the impression that once again they are not in too much of a hurry to resolve the complex questions. It is as if they were allowing other collectives to go ahead and then learn from their experience and mistakes.

This psychology of waiting and deliberately dragging out introduction is a serious brake on the work. Strange as it seems, some types of interference make themselves known more vividly as the automated system being introduced becomes more sophisticated. The Sigma is already beginning to run into a certain counteraction by those sectorial organizations whose job it is to develop and incorporate ASU's. The sectorial scientific research institutes and design bureaus have contract relations with the enterprises and their work is evaluated by the amount of work done on economic contracts.

They receive money from the plant for performance of all points of the contract: precontract examination, development of the technical specifications, contract design, and detail design, and introduction of the system. It turns out that the scientific research institutes and design bureaus are vitally interested in performance of precontract and design work, but adaptive systems are not needed or hardly needed at all in this work. What is left? Only introduction. But the plant can do that without middlemen. Progress in the setting up of ASU's demands a change in the workstyle of autonomously financed scientific research institutes and design bureaus. Otherwise, surprising as it may seem, these organizations may retard the progress of ASU's at enterprises while working in this precise area.

Designing control systems is creative work, a developing field that does not tolerate stereotyped approaches. But the ASU development and introduction procedures and the composition and design of systems have been rigidly defined by state and sectorial standards. A special document says that the ASU must have particular subsystems and problems. But all our work proves that an established, ratified list of problems and subsystems is an obstacle, a restraint, and holds back research projects. Scientific investigation cannot be constrained by standards or there will be no Sigma! When the system is accepted, then standards can be introduced.

Article 26 of the draft of the new USSR Constitution formulates an important point to the effect that the state insures planned development

of science and preparation of scientific cadres in accordance with society's needs and organizes the introduction of scientific research in the national economy and other spheres of life. Planning and purposefulness are also extremely necessary in important work such as introducing ASU's.

The collectives of the enterprises, scientists, engineers, and economists face an important national economic challenge: sharply cut the costs of building and incorporating systems while significantly improving their quality. The new Sigma automated control system is graphic evidence of the fact that this challenge can be met in a short period of time.

11,176
CSO: 1870

ELECTRONICS AND ELECTRICAL ENGINEERING

UDC 621.396.67

RADIATION OF A DIPOLE SURROUNDED BY A SPIRALLY CONDUCTIVE SPHERICAL SHEATHING

Kiev IZVESTIYA VYSSHIKH UCHEBNYKH ZAVEDENIY. RADIOELEKTRONIKA in Russian
Vol 20, No 8, 1977 pp 36-39

[Article by V. P. Belichenko and G. G. Goshin]

[Text] Radiation of an electric dipole surrounded by a spirally conductive spherical sheathing is discussed. Polarization of the field and radiation resistance are investigated.

Regardless of the availability of sufficiently complete experimental results on spherical spiral antennas, there is only one known work [1] in which the model problem of excitation of a spirally conductive spherical surface by a ring system of δ-generators is solved. That reference, however, does not discuss such important characteristics as polarization and radiation resistance. These characteristics are investigated in this article for the case when the exciting element is an electric dipole, placed within the spirally conductive spherical surface and oriented along its axis of symmetry.

Suppose that the dipole is placed at a distance r_0 away from the center of a sphere of radius a which is conductive along the spirals that run at an angle Ψ = const with respect to the meridians, and nonconductive in orthogonal directions. The fields will be expressed in terms of Debye electric potential U and magnetic potential V.

The free-space dipole field is determined by the single potential [2]

$$U^0 = -\frac{qw}{4\pi r_0} \sum_{n=0}^{\infty} (2n+1) P_n(\cos\Theta) \begin{cases} j_n(kr)\, h_n^{(1)}(kr_0), & r<r_0, \\ j_n(kr_0)\, h_n^{(1)}(kr), & r>r_0. \end{cases} \quad (1)$$

Here q is the dipole moment, w is the wave impedance of space, $j_n(x)$ and $h_n^{(1)}(x)$ are spherical Bessel and Hankel functions and $P_n(\cos\Theta)$ are Legendre polynomials.

Potentials of secondary field, generated by currents induced in the spirally conducting sheathing, will be sought in the following form:

$$\left.\begin{aligned} U^{\pm} &= \sum_{n=0}^{\infty} (2n+1) A_n^{\pm} P_n (\cos\Theta)\, z_n^{\pm} (kr) \\ V^{\pm} &= \sum_{n=0}^{\infty} (2n+1) B_n^{\pm} P_n (\cos\Theta)\, z_n^{\pm} (kr) \end{aligned}\right\}, \tag{2}$$

where the quantities with the "+" sign pertain to the region r < a and those with the "-" sign pertain to the region r > a, $z_n^+(kr) = j_n(kr)$ and $z_n^-(kr) = h_n^{(1)}(kr)$.

The unknown coefficients $A_n^{\pm}$ and $B_n^{\pm}$ should be determined from boundary conditions on the surface r = a which are analogous to the boundary conditions given in reference [1], i.e.,

$$\left.\begin{aligned} &(H_\Theta^- - H_\Theta^+) + \mathrm{tg}\,\Psi\,(H_\varphi^- - H_\varphi^+) = 0 \\ &(E_\Theta^0 + E_\Theta^-) + \mathrm{tg}\,\Psi E_\varphi^- = 0 \\ &E_\Theta^- = E_\Theta^+,\ E_\varphi^- = E_\varphi^+ \end{aligned}\right\}. \tag{3}$$

Substitution of (1) and (2) into (3) and consideration of formulas which express the field components in terms of Debye potentials result in a system of four algebraic equations for the unknown coefficients. The solution of this system for the region r > a has the following form:

$$\left.\begin{aligned} A_n^- &= \frac{q\omega}{4\pi r_0} \frac{j_n(kr_0) \frac{d}{dr}[rh_n^{(1)}(kr)]|_{r=a} \frac{d}{dr}[rj_n(kr)]|_{r=a}}{\Delta_n(ka)} \\ B_n^- &= \frac{iqka\,\mathrm{tg}\,\Psi}{4\pi r_0} \frac{j_n(kr_0)\, j_n(ka) \frac{d}{dr}[rh_n^{(1)}(kr)]|_{r=a}}{\Delta_n(ka)} \end{aligned}\right\}, \tag{4}$$

$$\Delta_n(ka) = (ka\,\mathrm{tg}\,\Psi)^2 j_n(ka)\, h_n^{(1)}(ka) + \frac{d}{dr}[rj_n(kr)]|_{r=a} \times$$

$$\times \frac{d}{dr}[rh_n^{(1)}(kr)]|_{r=a}.$$

Using asymptotic formulas (as $kr \to \infty$) for Hankel functions in (1) and (2), we obtain the following expressions for the far-field components:

$$\begin{cases} E_\Theta = wH_\varphi = -wka\,\mathrm{tg}^2\,\Psi\,\dfrac{e^{ikr}}{r}\displaystyle\sum_{n=1}^{\infty}(-i)^n\dfrac{(2n+1)}{\Delta_n(ka)}\times \\ \quad\times Q_n(a, r_0)\,h_n^{(1)}(ka)\,P_n^1(\cos\Theta), \\ E_\varphi = -wH_\Theta = -iw\,\mathrm{tg}\,\Psi\,\dfrac{e^{ikr}}{r}\displaystyle\sum_{n=1}^{\infty}(-i)^n\dfrac{(2n+1)}{\Delta_n(ka)}\times \\ \quad\times Q_n(a, r_0)\,\dfrac{d}{dr}[rh_n^{(1)}(kr)]\,|_{r=a}\;P_n^1(\cos\Theta), \end{cases} \tag{5}$$

$$Q_n(a, r_0) = q\,\frac{ka}{4\pi r_0}\,j_n(ka)\,j_n(kr_0).$$

For a dipole which is located at the center of the sphere ($r_o = 0$) we have the following instead of (5):

$$\begin{cases} E_\Theta = wH_\varphi = -ikqw\,(ka\,\mathrm{tg}\,\Psi)^2\,\dfrac{j_1(ka)}{4\pi\Delta_1(ka)}\,h_1^{(1)}(ka)\,\dfrac{e^{ikr}}{r}\,\sin\Theta, \\ E_\varphi = -wH_\Theta = qk^2\,aw\,\mathrm{tg}\,\Psi\dfrac{j_1(ka)}{4\pi\Delta_1(ka)}\,\dfrac{d}{dr}\,[rh_1^{(1)}(kr)]\,|_{r=a}\dfrac{e^{ikr}}{r}\,\sin\Theta. \end{cases} \tag{6}$$

For a meridian conductivity ($\Psi = 0$) the dipole radiation does not pass through the sphere, i.e., the sphere behaves as a shield. For azimuthal conductivity ($\Psi = \pi/2$) formulas (5) and (6) give the dipole field in free space, i.e., the sphere has no effect on the dipole radiation.

For a dipole which is located at the center of the sphere the coefficient of ellipticity is given by the expression:

$$K_e = \frac{E_\varphi}{E_\Theta} = \frac{\sqrt{1+(ka)^6}}{[ka+(ka)^3)]\,\mathrm{tg}\,\Psi}\,e^{\,i\left[\mathrm{arc\,tg}\,\frac{1}{(ka)^3} - \pi\right]}. \tag{7}$$

When the electric dimensions of the spherical sheathing are small ($ka << 1$), we have $K_e = i/ka\ \mathrm{tg}\ \Psi$, i.e., the field is elliptically polarized, becoming almost circularly polarized when $ka\ \mathrm{tg}\ \Psi \simeq 1$. In this case a spirally conductive sphere can be treated as a polarization transformer. When electric dimensions are large ($ka >> 1$), we have an inclined polarization with $K_e \simeq -\mathrm{ctg}\ \Psi$. If the dipole is displaced from the center, the coefficient K_e becomes a function of coordinate Θ and expansions (5) must be used for its calculation. Figure 1 shows the curves of $|K_e|$ (continuous curves) and of arg K_e (dashed curves), plotted for a dipole which is located at the pole of the spherical sheathing, when $\Psi = 45°$ ($1 - ka = kr_o = 1$, $2 - ka = kr_o = 2$). When ka is increased, the behavior of these curves becomes more drastic. Calculations indicate that this corresponds to the appearance of new lobes in the directive pattern.

The radiation resistance of an electric dipole which is located within and on the axis of a spirally conductive spherical sheathing, normalized with respect to the radiation resistance of a dipole in free space, is given by the formula:

$$\frac{R_\Sigma}{R^0_\Sigma} = 1{,}5\left(\frac{a\,\mathrm{tg}\,\Psi}{r_0}\right)^2 \sum_{n=1}^{\infty} \frac{n(n+1)(2n+1)}{|\Delta_n(ka)|^2}\, j_n^2(ka)\, j_n^2(kr_0) \times \tag{8}$$

$$\times\left\{\left|\frac{d}{dr}\left[r h_n^{(1)}(kr)\right]\Big|_{r=a}\right|^2 + (ka\,\mathrm{tg}\,\Psi)^2\left|h_n^{(1)}(ka)\right|^2\right\},$$

which was obtained by integrating the Umov-Pointing vector of a sphere of radius $r \to \infty$.

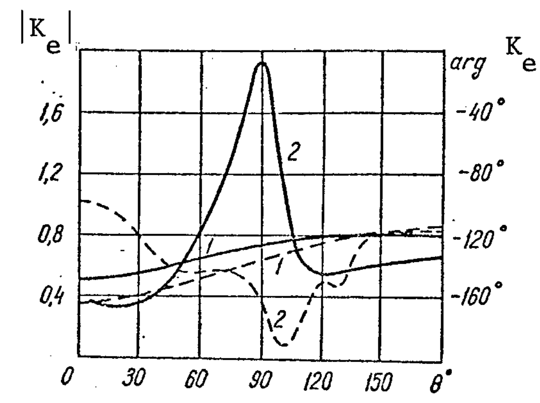


Figure 1

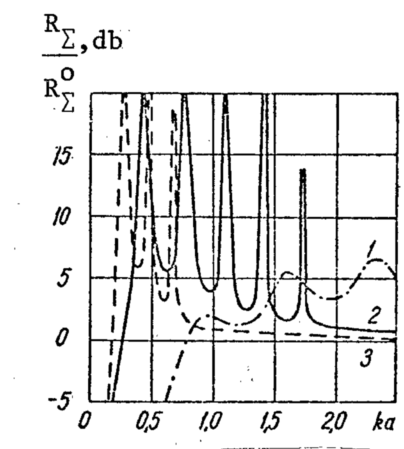


Figure 2

The radiation resistance is strongly dependent on the quantity $\Delta_n(ka)$ which appears in formula (8). As a matter of fact, an asymptotic analysis based on formulas which are valid when $n \gg ka$ and $n \gg 1$ and which can be found in reference [3], for example, indicates that Re $\Delta_n(ka)$ is small and decreases fast with increasing n, while Im $\Delta_n(ka) = 0$ when $n(n+1) = (ka\ \mathrm{tg}\ \Psi)^2$. This means that one harmonic can dominate over all remaining harmonics and that R_Σ/R^0_Σ can become resonant as ka tg Ψ is varied. This statement is supported by the results of computer calculations which are shown in figure 2 for a dipole that is located at the pole of the sphere. The curves of figure 2 are plotted for $kr_0 = ka$ and for tg $\Psi = 1$ (curve 1), tg $\Psi = 3$ (curve 2) and tg $\Psi = 5$ (curve 3).

It may be seen that for a specific value of tg Ψ and a variable ka resonance is achieved sequentially at a number of harmonic frequencies and that the radiation resistance of the dipole increases drastically at some frequencies in the presence of a spirally conductive spherical sheating. Application of asymptotic formulas, valid for ka > n(n + 1)/2, gives $|\Delta_n(ka)|^2 \simeq \cos^2(ka - n\pi/2) + tg^4\Psi \sin^2(ka - n\pi/2)$ which indicates that the resonant phenomena are absent and that the curves behave smoothly beyond the region of resonances. In that case $R_\Sigma > R^o_\Sigma$, i.e., the sheathing has practically no effect on the dipole radiation resistance. If the dipole is placed at the center of the spherical sheathing ($r_o = 0$), only the term with n = 1 will remain in formula (8) but the arguments presented above will not change.

In conclusion, let us point out that similar resonant phenomena are also observed in dipoles surrounded by spherical magneto-dielectric sheathing [4, 5] or in the presence of an impedance sphere [6].

BIBLIOGRAPHY

1. Mei, K. K.; Meyer, M. "Solutions to Spherical Anisotropic Antennas", IEEE TRANSACTIONS, AP-12, No 4, p 459, 1964.

2. Markov, G. T.; Chaplin, A. F. "Vozbuzhdeniye elektromagnitnykh voln" [Excitation of Electromagnetic Waves], Moscow, Energiya, 1967.

3. Ivanov, Ye. A. "Difraktsiya elektromagnitnykh voln na dvukh telakh" [Diffraction of Electromagnetic Waves on Two Bodies], Minsk, Nauka i Tekhnika, 1968.

4. Vol'pert, A. "On the radiation resistance of a dipole surrounded by a spherical magneto-dielectric sheathing", RADIOTEKHNIKA, vol 3, No 6, p 6, 1948.

5. Shafai, L.; Chung, R. K. "Resonance Effects in Slotted Spherical Antennas Coated With Homogeneous Materials", CANADIAN JOURNAL OF PHYSICS, vol 51, No 22, p 2341, 1973.

6. Wait, J. R.; Jackson, C. M. "Resonant Characteristics of a Corrugated Sphere", JOURNAL OF RESEARCH OF THE NBS, vol 67-D, No 3, p 347, 1963.

Submitted 14 April 1975; resubmitted after revisions 1 December 1975

9068
CSO: 8144/0404

PREDICTION AND EXPLORATION IN GEOLOGY

Moscow NAUKA I ZHIZN' in Russian No 11, Nov 1977 pp 76-82

[Article by Professor Ye. Kozlovskiy, Doctor of Technical Sciences, USSR Minister of Geology]

[Text] During the years of Soviet rule Soviet geology was transformed into a highly developed branch of knowledge. The achievements in science and technology, especially radioelectronics, instrument making and machine building are being used more and more with each passing year.

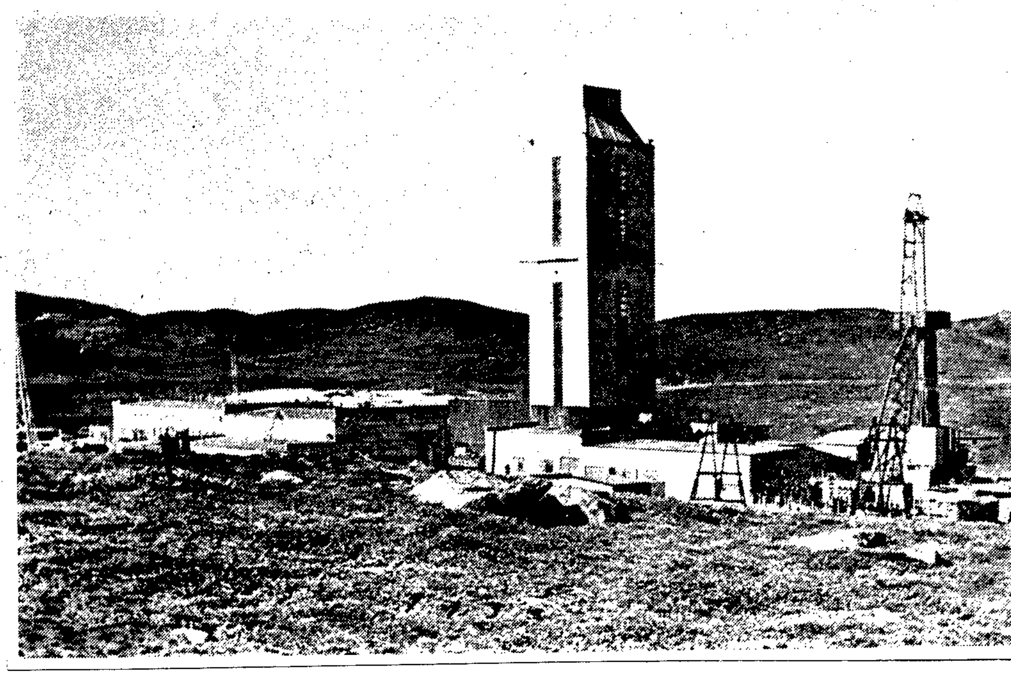
The tasks assigned to Soviet science and technology during 1976-1980 require an improvement in the technical outfitting of geological prospecting work, the creation and practical introduction of new highly productive equipment, automated drill rigs, apparatus, and instruments. It is necessary to broaden the use of progressive geophysical and geochemical methods and make use of space vehicles and high-altitude aircraft in geological research.

All this is necessary for the successful solution of highly important problems: increasing mineral-raw material resources, especially in regions with already operating mining enterprises and in newly exploited regions of the country.

In the value of all the raw material used by our industry, more than two-thirds is now accounted for by mineral raw material. This includes about 150 types of minerals extracted from the earth. Such is the contribution of our science and the half-million personnel engaged in Soviet geological exploration to the national economy of our country.

The discovery of a deposit. Behind these words is hidden long work by a large body of specialists with work in several stages. Geological "forecasters," working with maps, define the most promising areas for exploration. Then geological field workers take over: expeditions go out into the field and return with the "addresses of mineral deposits." The task of field geologists is to give a detailed description of the deposit. Only after this is it possible to speak of the discovery of a new deposit.

The modern geologist investigates promising regions and seeks definite minerals. His prediction work is directed along both these lines.



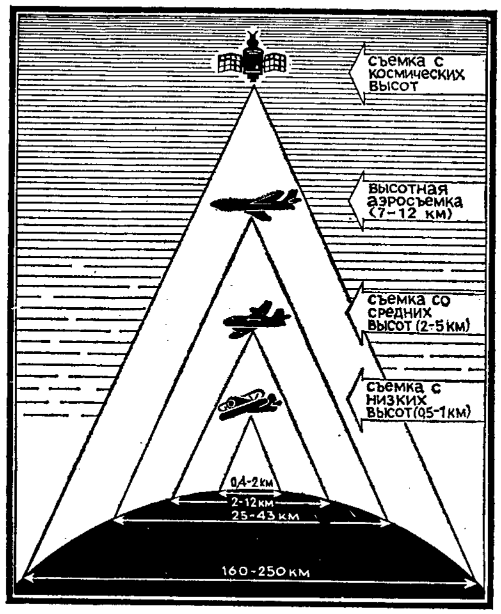
The Kola superdeep hole. The second drilling stage is in progress.

Examples of successful geological predictions are well known. The Yakutskaya diamond-bearing province, the tin-bearing zones of Transbaykalia and Primor'ye and many petroleum- and gas-bearing regions were predicted in the quiet of geological offices.

In order to broaden and refine knowledge in the field of theoretical geology superdeep boreholes are planned and in some places have already been drilled in the Soviet Union: in the Caspian region, in the Ukraine and in the Northern Caucasus. As of today it is the Kola superdeep hole which has gone the deepest: by the end of the current five-year plan it should reach the level 10.5 km. And this means that it will pass through the boundary of the granite and basalt layers of the earth's crust. We know that at this discontinuity there is a marked change in the velocity of seismic waves, but it is still difficult to say what rocks lie above and below this boundary, what their structure and composition is, and what exactly may be the nature of the discontinuity, although these questions are very important for geology.

The Kola superdeep hole is now the deepest of those which have been drilled in the crystalline rocks of the Precambrian. Already in the first stage of drilling geological science has been enriched by much new, sometimes

unexpected information. For example, earlier it was assumed that in ancient crystalline formations the temperature of the deep layers increases with depth by one degree each 100 meters. And in actuality, with drilling to a depth of two kilometers this hypothesis was confirmed. At deeper horizons it was found that the heating increases far more rapidly. At seven kilometers from the surface a temperature of about 70°C was expected, but it was found to be 120°C.



Scanning of earth from different flight altitudes. Annotations, from top to bottom: survey from space altitudes, high-altitude aerial survey, survey from intermediate altitudes, survey from low altitudes.

Geologists stated with assurance that at great depths the ancient earth's crust is dead: the rocks there are impermeable, without aqueous solutions, and gases do not move in them. However, during drilling in Precambrian rocks there was found to be hydrogen, helium, carbon dioxide and methane. At a depth greater than 6 kilometers the borehole encountered a brine spring. Rocks with an age of more than two billion years were found to contain remnants of living organisms. The dead horizons were "alive," to be sure, in a geological sense.

Every sample of the rocks raised from the boreholes has been thoroughly investigated. These "messengers" from the earth's depths helped in establishing how the content of elements in rocks changes with depth. For example, near tectonic dislocations there was found to be an increase in the content of lead, zinc and copper. It was also established that the gases from the rocks are drawn into the fissures, enriching the solutions circulating in them.

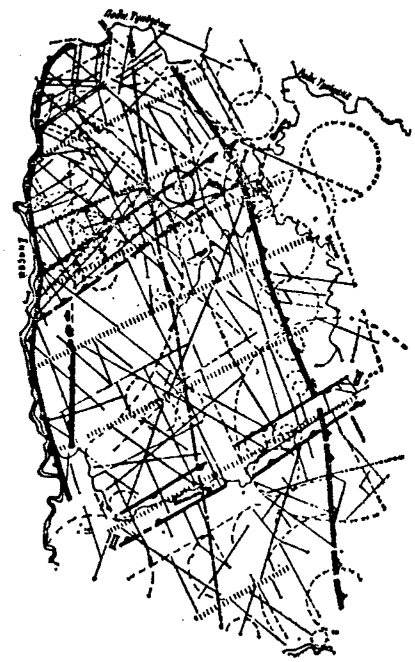


Diagram of tectonic dislocations in the Yenisey Ridge region. Compiled on the basis of data from interpretation of television photographs.

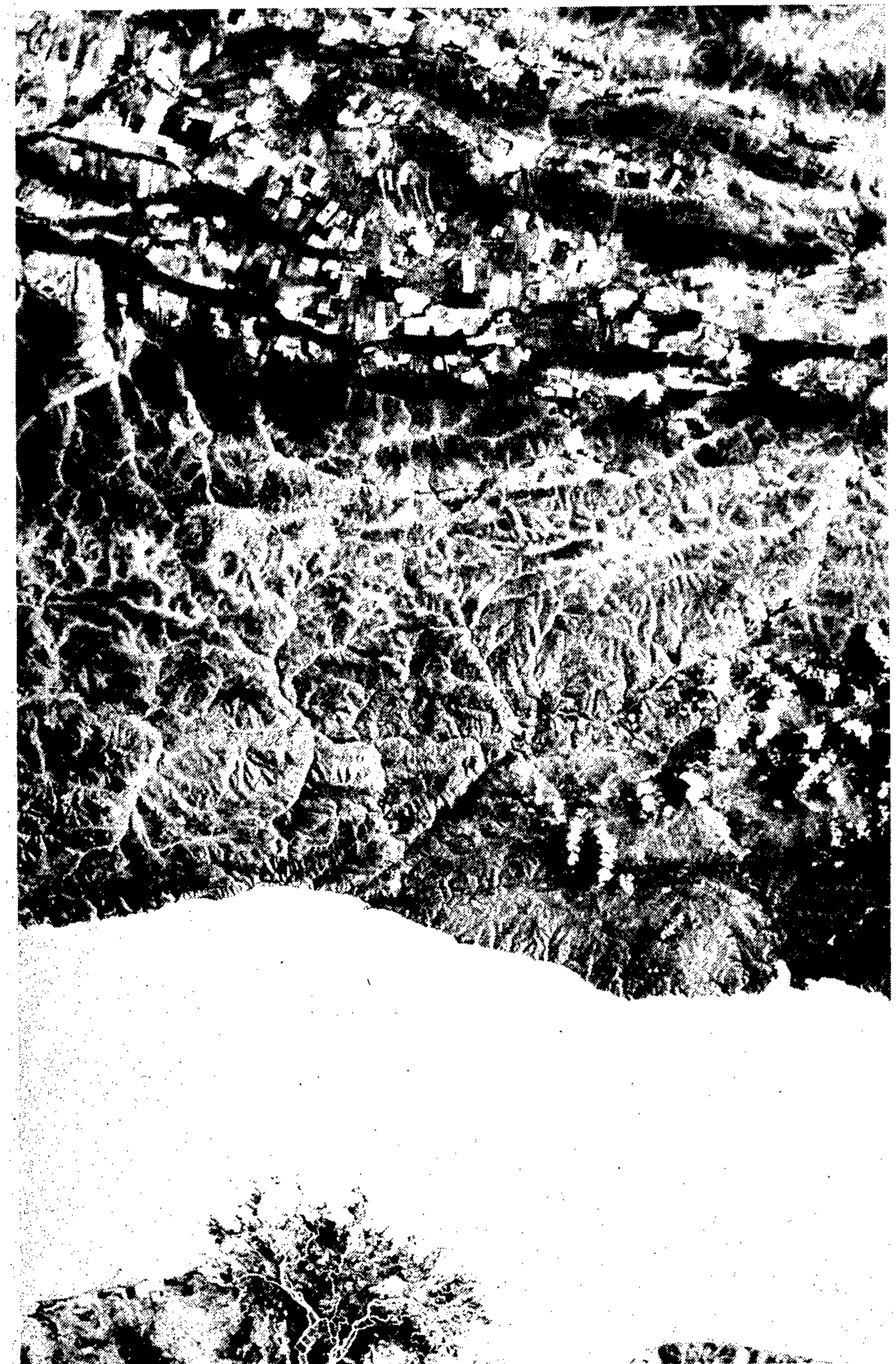
At great depths in the crystalline complex there was subsequently found to be thick zones of rocks with reduced density. They were evidently formed as a result of movement of individual layers relative to one another. These new data are important for theoretical geology which is working on a global theory of the formation and evolution of the earth's crust.

The information provided by the Kola superdeep hole will clarify the picture of general structure of the deep layers.

The data on the deep layers collected from beneath the earth are supplemented by information received from space.

When artificial earth satellites were launched into space geologists were among the first who understood the enormous possibilities which had opened up before science by the viewing of the earth from a great altitude. A camera raised to an altitude of 500-1,000 m scans a strip with a width up to two kilometers. From an altitude of two to five kilometers it takes in a strip up to 12 kilometers wide and a single photograph will show a territory with an area not greater than 700 square kilometers. A single photograph from a high-altitude aerial survey will show a maximum of several thousand square kilometers.

Cosmonauts have surveyed the earth's surface from an altitude of hundreds of kilometers and have returned photographs each of which shows areas of tens of thousands of square kilometers. From artificial earth satellites of the "Meteor" and "Kosmos" types the television camera takes in an area of hundreds of thousands of square kilometers!



Region of Lake Baykal photographed from aboard "Soyuz-22" spaceship. The photograph shows the lake, river and mountains.

A space photograph shows major geographic and geological features: the mountains merge into chains, geological structures are joined into systems. A generalization of the terrain image occurs.

On space photographs one can clearly see structural elements of the earth. They "peek" through the upper layer of the unconsolidated deposits, like one can make out the contours of a statue before the solemn moment of its unveiling. The earth's crust seemingly is probed and geologists can see the plan of the lower stage. We can see this not by penetrating into the deep layers but by rising into space.

The new information has forced us to take a critical view of many long-established scientific concepts concerning the structure, age and position of large folded systems, deep faults, oceanic depressions and volcanic zones.

I have told only about two sources of information which have enriched modern theoretical geology. But there are many. Geophysics has at its command a great variety of methods for learning about the deep layers. By means of geophysical methods it is possible to register the seismic waves penetrating the entire earth, electric currents and the heat flows emanating from the deep layers and it is possible to study the distribution of gravity... By bits and pieces we have collected all the information now available on the deep layers, thereby learning as much as possible concerning the structure of the earth and especially about the earth's crust -- the storehouse of all mineral resources. The theories and hypotheses of its origin and structure are being developed and improved, in particular, the new theory of the tectonics of lithospheric plates, which is now being actively discussed by specialists. Geological explorers are expecting from this theory specific recommendations of assistance in the purposeful search for minerals at deep horizons.

The centuries-old and at one time the only method for geological exploration is being used less with each passing year. Now aerospace methods are being widely introduced. They provide the geologist with aerial and space photographs and materials from different surveys: radar, IR, multizonal, magnetic, radiation and X-ray... The earth's surface has dozens of different "faces" and each contains useful geological information. This has led to revolutionary changes in exploratory geology.

Five minutes of a photographic survey from space can yield as much information as it would take a geological party ten years to collect. Now our country's first space photogeological map of the region of the Baykal-Amur railroad route is being compiled. It will cover an area of 1.5 million square kilometers and concentrates all information on this region and will make it possible to carry out a purposeful implementation of geological reconnaissance and exploration.

There has been a considerable improvement in a traditional aerial photographic survey. One of its new forms is a multizonal survey. Such a survey is carried out in different zones of the visible spectrum and supplies qualitatively new information in comparison with an ordinary photograph.

In addition, there is automatic interpretation of aerial photographs. The human eye is a universal and fine instrument but it is less disciplined and discriminating than systems of glass and metal. And less rapid. Accordingly, some stages in interpretation will be handed over to automated systems.

Geologists have learned to read the images, unseen earlier, in which the earth appears as the totality of physical parameters. Not mountains, rivers and plains are seen in these images, but let's say, the distribution of temperatures in this particular sector, soil moisture content, rock porosity, etc.

Methods have already been created for an analysis of optical, thermal and electric properties of geological features. Effective methods have been developed for the remote determination of the mineralogical composition of rocks and minerals by nuclear physics, gamma spectrometer, petrographic and geochemical methods.

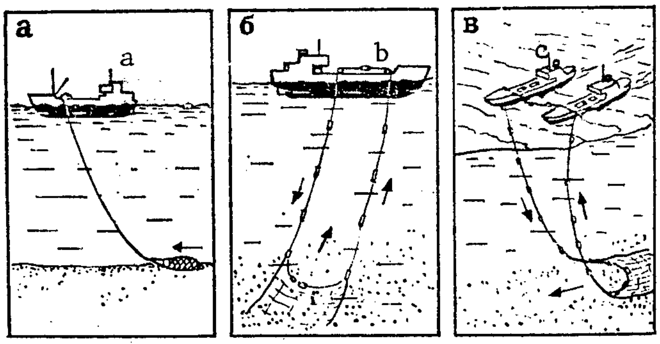
Using a thermal IR survey it is possible to study volcanic regions, detect inundated territories, solve geological survey, hydrogeological and geological engineering problems.

In the Soviet Union specialists have used radar in surveying millions of square kilometers. Neither a dense cloud cover nor nighttime darkness can prevent the obtaining of an image resembling ordinary small-scale aerial photographs.

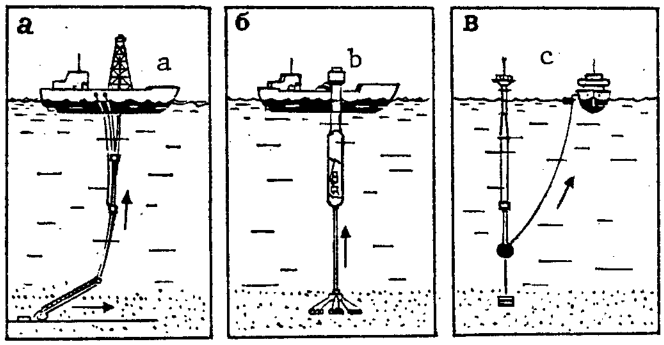
A radar survey is indispensable for an investigation of inaccessible regions. It is used in those places where there is always bad weather and where the taking of ordinary photographs is impossible. For example, on the Taymyr Peninsula there is clear weather only three or four days a year. It would take many years to complete an aerial photographic survey of the peninsula. Still more time would be required for the geologists to study the hundreds of thousands of square kilometers of the inhospitable peninsula. But using the "Toros" radar system the Taymyr was surveyed in a week.

So a geological survey and exploration are completed by the compilation of a series of geological maps showing the location of mineral deposits. But it is too early to say: there's a deposit! It must be confirmed.

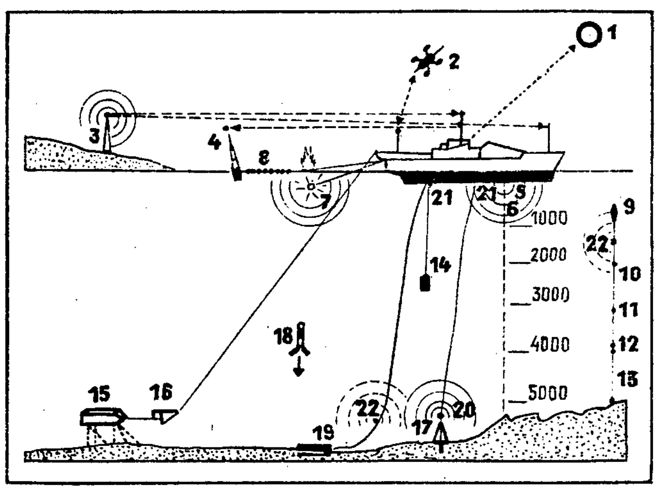
Technical and cultural-living bases are set up in uninhabited places. Geologists carry out drilling, digging and repair work and establish modern laboratories: mineralogical, chemical, spectral...



1.



2.



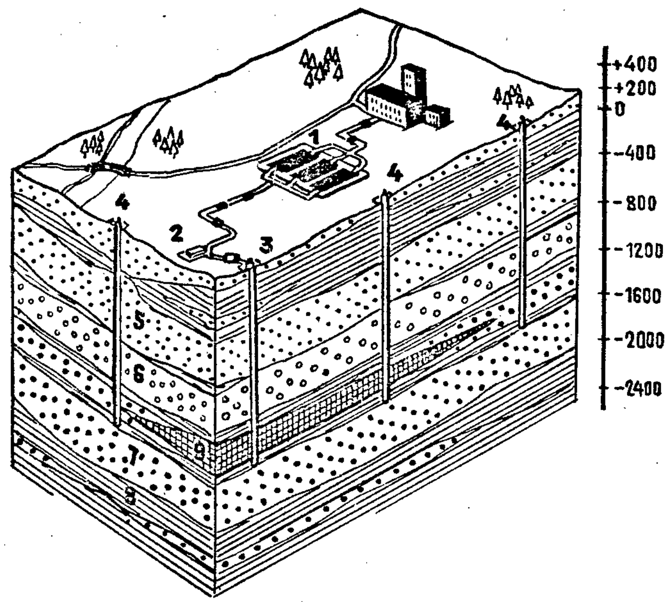
3.

The world ocean is an abundant source of different types of mineral raw materials: petroleum, gas, tin, ferruginous sands, diamonds, titanium-bearing minerals, zircon, monazite, phosphates, amber, sand and gravel. Exploratory work in the regions of the coastal zone and in the open ocean and the production of nodules from the ocean floor is being carried out using modern means, some of which are shown in the figures.

1. Cable-bucket apparatus for deep-water work: a) scraping dredge; b) apparatus with endless cable and buckets; c) variant of apparatus with endless cable and buckets for work from two ships.

2. Hydrotransport apparatus for deep-water working of nodules: a) airlift; b) with submergible bottom suction apparatus in capsule; c) apparatus with submergible pumps.

3. Principal technical means for oceanological investigations. Navigation systems: 1) astronomical; 2) satellite; 3) radar; 4) radio buoy. Bathymetric investigations: 5) narrow-beam profilograph; 6) echo sounder. Seismic exploration: 7) source; 8) string of seismic detectors. Oceanographic investigations: 9) underwater measuring system with anchored buoy; 10) current meter; 11) thermometer; 12) pressure-sensitive detectors; 13) lowered anchor; 14) deep probe for continuous registry of temperature, salinity, speed of sound and pressure. Geological research: 15) platform with TV and still cameras and illumination; 16) stabilizing platform; 17) corer; 18) self-contained sampler; 19) dredge. Distribution of underwater instruments: 20) "pincher"; 21) hydrophone; 22) source.



Particularly toxic concentrated waters which are difficult to purify and also technically pure waters which are still not exploited are sometimes stored in the earth's deep layers for possible later use. According to the basic laws of the USSR and the union republics this is admissible only in exceptional cases with adherence to special requirements and conditions. Safe storage methods for runoff are being developed by geologists and hydrogeologists. The figure is a diagram of storage of industrial waste water in deep water-bearing strata. Diagram of storage of industrial waste water in deep water-bearing strata: 1) accumulating containers; 2) pump; 3) pressure borehole; 4) observation boreholes; 5) zone of active water exchange (fresh ground water); 6) zone of slowed water exchange (brackish ground water); 7) zone of stagnant regime (saline ground water and brines); 8) water-impermeable rocks; 9) pumped industrial wastes

The most reliable method for inspecting the earth's deep layers is to obtain from the necessary depth a sample of the rocks or ores. In order to get a rock core with a diameter of several centimeters it is necessary to erect drill rigs at the surface. Many thousands of such drill rigs work around-the-clock throughout our entire country. In the last year of the Ninth Five-Year Plan the coring method was used in the drilling of 18.6 million meters of boreholes. During the last year of the Tenth Five-Year Plan plans call for the drilling of 21.5 million meters.

Exploratory penetration into the earth's deeper layers is now accomplished primarily using diamond bits: the country's industry now has an adequate quantity of artificial and natural diamonds. Using these, the best drilling crews of the Geology Ministry have been able to achieve an earlier unprecedented drilling rate. In 1976 the master driller A. Ye. Nitsak of the Mamsko-Chuyskaya Expedition was awarded the State Prize. Penetrating through hard rocks, his team drilled boreholes with a mean rate of more than 1,000 meters per month. The young drillers B. Ivannikov, V. Astaf'yev, A. Vetrov and others became recipients of the Leninskiy Komsomol Prize.

Each year of the Five-Year Plan brings to drillers new kinds of rigs and technical apparatus, as well as advanced technology. Only recently the rate of rotation of the drilling tool exceeding 1,000 rpm had just been achieved, but now in experimental polygons there are already rigs making possible the achievement of considerably greater rates. The introduction of new equipment increases the technical level of production and considerably facilitates the work of drillers.

In 1976 the State Prize was awarded to the specialists of the Special Design Bureau of the Scientific-Production Combine "Geotekhnika" and the workers of a number of geological prospecting expeditions for the development and introduction of the highly efficient "hydroimpact" drilling method. The work was directed by Doctor of Technical Sciences L. E. Graf and the chief of the special design bureau A. T. Kiselev. They succeeded in transforming into reality an ancient idea of drillers -- combining the principles of impact and rotation, forcing them to work together.

"Hydroimpact" apparatus is installed at the lower end of the drill column -- in front of the bit. As a result, the bit "chisels" the rock with a greater frequency: thousands of impacts per minute. And the bit rotates. The impacts force it into the rock and the rotation cuts off the "crests" arising under the impacts.

During the Ninth Five-Year Plan the "hydroimpact" method was used in drilling more than 1,700,000 meters of boreholes. The new drilling method gave a savings of several million rubles. During the Tenth Five-Year Plan this type of apparatus will be used in doing still more work.

The production successes with "hydroimpact" apparatus are attracting the attention of foreign specialists. The latest models are being exported to many countries.

This year, near the city of Rechitsa, in Gomel'skaya Oblast, specialists are testing the "Uralmash-125A" outfit, capable of drilling boreholes to a depth as great as 4,000 m. This is the world's first automated drill rig, the first of those which, according to the "Fundamental Directions in the Development of the USSR National Economy During 1976-1980," will be introduced into the national economy.

The control panel is the brain of the drill rig. Sitting at the control panel, the driller receives information from the numerous sensors situated at key points in the complex drilling system. He receives such a quantity of information which he could not receive if he were situated alongside the mechanisms. The drilling operator has only one assistant. The entire watch consists of only two men.

The automatic drill rig will introduce serious changes in the complex drilling business. It will make it possible to drill constantly with a high productivity, adapting the drilling regime flexibly to the deep conditions encountered. Control of this process can be assigned to an electronic computer. It will receive information from the sensors of the automated drill rig, and in turn control signals are sent to the rig. These commands will very precisely and objectively evaluate the situation in the deep layers. The computer is capable of taking into account any number of factors exerting an influence on the drilling process. It can send signals to many outfits belonging, shall we say, to some expedition, trust or even larger organizations.

Drilling is a reliable method for exploring the depths, but it is expensive: the lion's share of the funds spent by geological prospecting expeditions is for this purpose. Geophysical prospecting is far, far cheaper. It does not require penetration into the deep layers and does not require the destruction of rocks. Sensitive instruments at the earth's surface detect information emanating from the deep layers and collect this information by bits and pieces. Geophysicists interpret the records of the instruments and on this basis get a picture of the deep layers.

In the five-year plan particularly great hopes are placed on the effectiveness and quality of exploratory geophysics. Precisely it is capable of raising the overall efficiency of geological exploration work in all stages and for a great number of minerals. Geophysical investigations give geologists information about the structure of the deep layers not only before drilling begins or expensive shafts are dug, but during the entire time in the course of this work it directs this work more precisely toward the sought-for objects. This gives a savings of time and money. Therefore, the "Fundamental Directions for Development of the USSR National Economy in 1976-1980" point out the necessity for broadening the use of progressive geophysical methods as one of the principal means for scientific-technical progress in geological prospecting work.

The greatest attention of geophysicists in our country is being devoted to exploration work to find petroleum and gas.

Energy forecasts predict that fuel consumption will increase. This means that the problems involved in petroleum and gas reconnaissance and exploration will continuously become more complicated. It is up to exploratory geophysics to solve these problems.

In order to find traps (places of accumulation of hydrocarbons) it is common to use seismic prospecting. The seismic oscillations excited by an explosion, impact or vibration are picked up by dozens of highly sensitive seismographs and are automatically registered and then are processed by means of high-speed electronic computers. However, not every trap contains petroleum or gas; they may be filled with water or may be empty. Therefore, it is important to have means for the direct detection of petroleum or gas. For example, each accumulation of hydrocarbons "smells," forming a faint gas aureole around it. It can be detected by geochemical methods. Deposits of hydrocarbons change the physical properties of the environment and this can be detected by precise geophysical investigations. Other directions then will also be developed, in particular, three-dimensional geophysical methods, making simultaneous use of observations at the surface and in boreholes, seismic holography, mathematical modeling, etc.

Among the solid mineral deposits which will be objects of the impending geophysical investigations will be, most importantly, iron, copper, lead, zinc, tin, bauxite, gold, diamonds and potassium salts. Ore geophysics has great possibilities for their detection. Use is made of seismic and electric prospecting, magnetometric and gravimetric surveys, investigations in boreholes, nuclear physics and electrochemical methods.

In modern geophysical surveying it is necessary to detect very weak necessary signals against a background of strong interference. Therefore, the principal direction in scientific and technical progress in exploratory geophysics is an increase in accuracy and resolution of apparatus and instrumentation and introduction of digital registry, making it possible to carry out the processing of data on electronic digital computers.

Every fifth geological prospector in the country is a geophysicist. We have laid great hopes on our earth physicists; they are capable of rapidly and with minimum costs carrying out investigations of the earth's deep layers.

I would especially like to define the economics of mineral raw materials and geological prospecting work. This field of geological science deals with the problems of the raw material base and studies the patterns of its development. Economic investigations are highly important in many scientific organizations of the Geology Ministry and guide the activity of working geologists. This is a guarantee of a further increase in the economic effectiveness of reconnaissance and exploration work.

In geological prospecting, as in no other field, the human qualities of each person in the detachment of geologists have always been important. Prospectors at all times worked in remote, frequently totally isolated places, without good communication with their comrades and with home. Work under such conditions requires endurance, purposefulness, the ability to do work with dedication in any situation.

These qualities in full measure are characteristic of today's geological field workers: geologists, geophysicists, drillers and diggers of shafts and drifts...For their achievements in establishing the mineral raw material base of the country orders and medals of the Soviet Union were awarded during the Eighth Five-Year Plan to 4,877 persons; during the Ninth Five-Year Plan awards were given to 5,100 geological field workers and 49 representatives of the geological service were designated Hero of Socialist Labor.

5303
CSO: 1870/155

POSSIBILITIES OF EARTHQUAKE PREDICTION

Moscow NAUKA I ZHIZN' in Russian No 10, 1977 pp 76-83

[Article by V. Tyurin]

[Text] The prediction of earthquakes -- the most awesome of calamities, caused by the tectonic forces of our planet -- is one of the most complex problems facing scientists. It is exceedingly important to know about the impending event, to know about all its possible consequences, in advance. All this is particularly true of populated regions. The journalist V. Tyurin visited several laboratories and institutes engaged in solution of the problem of earthquake prediction. This article tells about the achievements in seismology.

*****

The opinion has been expressed that during recent years earthquakes have become more frequent. To say the least, such a thought does not give cheer and comfort. Earthquakes have long resulted in great losses, suffering and loss of human life. True, specialists have calculated that other calamities, such as hurricanes, typhoons and storms, take a greater number of victims. But is that any consolation?

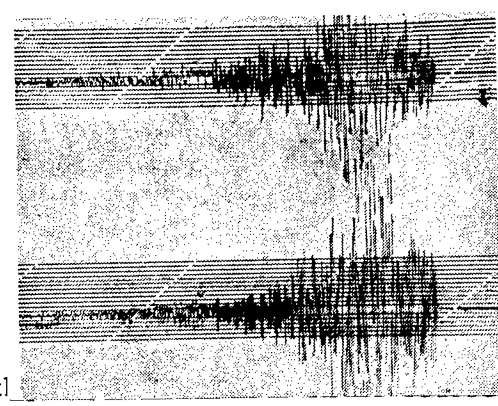
How do things stand with earthquake prediction? What are scientists thinking about and doing in this direction? What protective measures are being proposed?

The search for answers to these questions has immediately revealed the following circumstance: strong earthquakes are rare. For example, the widely known Soviet seismologist Corresponding Member USSR Academy of Sciences Yevgeniy Fedorovich Savarenskiy dedicated 45 years to his science and only once did he experience an underground tremor with a force of seven scale units; this was one of the aftershocks of the Tashkent earthquake of 1966. Other specialists have more personal experience, but not a great deal more. As seismologists joke, earthquakes prefer to occur without them...

In general, about 100,000 earthquakes occur annually on the earth, but most of them are sensed only by instruments. For each thousand scarcely sensed (4-5 scale units) earthquakes there is one destructive (7-9 scale units)

event, and a catastrophe (10 or more scale units) occurs once per 100,000 tremors with 4-5 scale units....

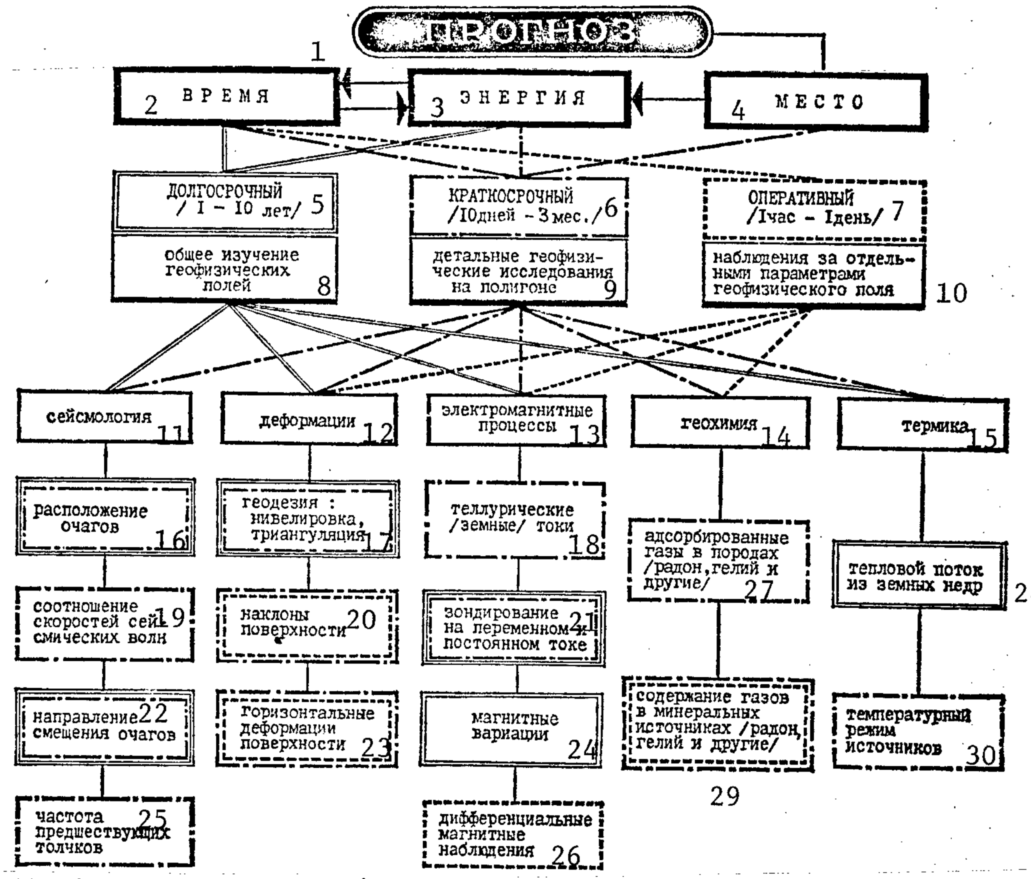
Control panel of seismic station in Sochi city.



Seismogram of eart[illegible] 1970. One can see the characteristic increase in the amplitude of the oscillation and the sharp cutoff after the earthquake: the unstable state of the rocks gave way to a new position of equilibrium.

And this unquestionably fortunate circumstance puts scientists in a difficult position: how to study earthquakes? It was precisely strong earthquakes which Academician B. B. Golitsyn, one of the founders of seismology,

had in mind when he figuratively called an earthquake a "lantern" which illuminates the earth. It is particularly important to predict strong earthquakes. But they are rare. [This somewhat simplified diagram shows the number of different observations which must be used in seismic forecasts. A mere one or two criteria cannot be used since only their sum can give a reasonably reliable picture of the state of deep layers (according to data from Ye. F. Savarenskiy and I. L. Nersesov).



1) Prediction
2) Time
3) Energy
4) Place
5) Long-range 1-10 years
6) Short-range 10 days-3 months
7) Routine 1 hour-1 day
8) General study of geophysical fields
9) Detailed geophysical research in polygon
10) Observations of individual parameters of geophysical field
11) Seismology
12) Deformations
13) Electromagnetic processes
14) Geochemistry
15) Thermal study
16) Location of foci
17) Geodesy, leveling, triangulation
18) Telluric (earth) currents
19) Ratio of velocities of seismic waves
20) Surface tilts
21) Sounding using a-c and d-c currents
22) Direction of focal displacement
23) Horizontal surface deformations
24) Magnetic variations
25) Frequency of earlier tremors
26) Differential magnetic observations
27) Adsorption gases in rocks (radon, helium, etc.)
28) Heat flux from depths
29) Gas content in mineral sources (Ra, He, etc.)
30) Temperature regime of sources

On this subject the following are the thoughts of Ye. F. Savarenskiy:

"The opinion that earthquakes have become more frequent is only partially true. In general, the annual variations of the frequency of underground tremors on the earth, including strong earthquakes, are within normal limits. But when strong earthquakes occur in the ocean or in poorly populated regions they do not attract attention. Now, however, they have seemingly shifted to densely populated regions, especially in Eurasia. There, of course, they cause much damage and much is written and spoken about them. What has caused this 'shift'? It has been postulated that some role is played by tide-generating forces -- gravitational effects of the sun and moon on the earth..."

Here our discussion shifted to the factors causing earthquakes. It must be said that people already began to seek them in very ancient times.

Now it can be said in short that the direct cause of an earthquake is deformation of the earth's crust (dilatation, compression, warping, twisting, etc.), which causes elastic stresses in rocks. When these stresses "get the upper hand" over the strength of rocks an earthquake occurs. But what forces cause the earthquake itself? That is the key question. Unfortunately, different answers have been given to this question and this is a real indication that the truth has not yet been discovered.

Most researchers feel that the "roots" of the phenomenon are in the earth itself. But Yevgeniy Fedorovich began to expound a hypothesis on the external factors and we will hear him out. We state at once that here all the hypotheses are set forth in a simplified, schematic form.

Ye. F. Savarenskiy: When the moon is at the perigee of its circumterrestrial orbit (that is, closest to the earth), its tide-generating force is 40% greater than at apogee (at the most distant point in orbit). It can be postulated that these forces cause dilatation of the earth's crust, that is, its deformation, which in turn leads to elastic stresses in some part of the planet.

However, this may not be a cause-and-effect situation, but a simple coincidence. For example, at Tashkent in 1966, some of the aftershocks coincided with the corresponding phases of the moon, whereas others did not. In short, a clear correlation has not yet been established. The same can also be said of the interaction of the electric and magnetic fields of the earth. It is postulated that they also exert an influence on motion of the earth's crust and thereby on seismicity. Whatever may be the case, the energy effect of these forces is insignificant and I think that they cannot cause an earthquake as such. It may be that in exceptional cases they can serve as a "triggering mechanism."

Probably the main "charge" of earthquake energy is hidden in the earth's deep layers. But where?

The San Andreas fault, with numerous transverse faults, runs through California. Here two blocks of the earth are displaced relative to one another. If a wedging action occurs an earthquake is inevitable.

Magnetologists (earthquakes are studied by scientists in different fields of specialization) advance the following hypothesis. Within the earth there is an outer liquid (molten) core in which a solid subcore "floats"; the latter is a mass with a radius of about 1,300 kilometers. It moves in

an ellipse and its approach to the surface can lead, they assume, to an increase in the deforming forces and therefore to seismicity. The authors see a confirmation of the hypothesis in the major earthquakes which during the past year have occurred in China, in the Philippines and at Gazli: during this period the subcore "floated up" close to the Himalayas (the drift of the subcore in a definite way exerts an influence on the earth's magnetic field and this makes it possible to trace it).

Indeed, most specialists feel that deformations of the earth's crust go hand-in-hand with its tectonic movements. The crust is divided into blocks (or "plates") which move relative to one another. And in those places where the plates come into contact with one another there are earthquakes.

Corresponding Member USSR Academy of Sciences V. L. Barsukov has expressed an interesting hypothesis. The essence of this hypothesis is that in the history of the planet the position of the earth's poles changed several times and in each case this was associated with active tectonic movements and mountain formation. Thus, 400 million years ago the magnetic pole moved from Western Australia to a point to the east of Japan. Two hundred million years later, when the Andes and Cordilleras, the Urals and Tibet were formed, the pole again moved, this time to its present-day position. Probably, the next movement of the poles (both magnetic and geographic) is possible in the present geological epoch. And in actuality, scientists note that the north geographic pole is now being displaced toward North America at a rate which is great by geological standards.

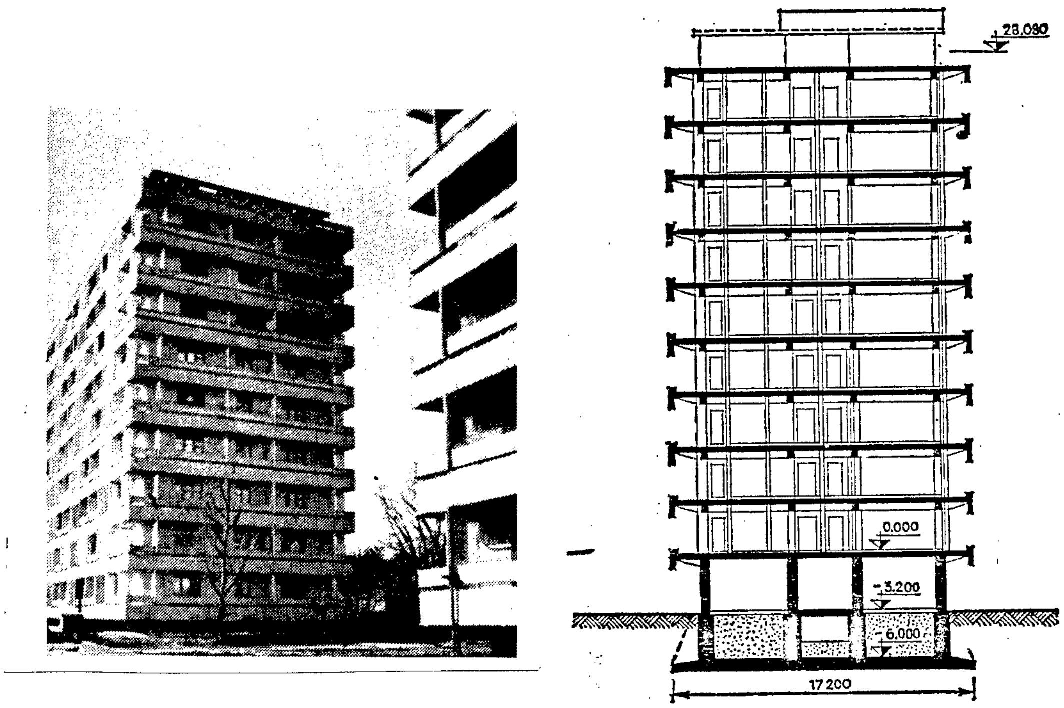
And once there is a change in the position of the axis of rotation, the motion of crustal blocks is intensified. In those regions which are in the zone of the new equator, the linear velocity of rotation increases, whereas at the new poles it decreases. Under these conditions "friction" is inevitable and the strongest friction is primarily at the equator and in the zones between 35 and 40 degrees north and south latitude. That is precisely where before our very eyes we have seen the strongest earthquakes of recent years...

As we see, all the hypotheses suggest that an earthquake happens when the increasing stress in the earth's crust exceeds the tensile strength of the rocks.

However, the recent studies of scientists, in particular, specialists of the Institute of Physics of the Earth imeni O. Yu. Shmidt USSR Academy of Sciences, where Ye. F. Savarenskiy also works, show that it can also be otherwise.

Ye. F. Savarenskiy: The fact is that the mechanical properties of rocks, especially in regions where active tectonic processes and mountain formation are occurring, do not remain constant. There is an increase in the fissuring of rocks and very fine fissures appear. The scientists of our institute feel that under the influence of constant stresses in the earth's

crust the formation of fissures begins to increase and at some moment in time this process becomes like an avalanche. Then an earthquake occurs.



In the photograph: a nine-story apartment building in the "Ukrainskiy" district in Tashkent. In the cross section of the building one can see the thick foundation, deep cellar and reinforced floors and ceilings. Earthquakes are no threat to such a building.

American researchers feel that microfissures and the very small pores which exist even in the most solid granites are filled with fluid, which also causes a strong decrease in rock strength.

Both hypotheses lead to one and the same conclusion: an earthquake can also occur when there are constant, stable stresses in the earth's crust -- at the time when there is a decrease in rock strength.

As we see, there are many hypotheses (there are far more than we have mentioned). But which of them is correct? Or is each at least partially correct? In order to know the truth, it is necessary to look into the focus of the earthquake at a depth of tens and sometimes hundreds of kilometers. But modern science cannot do this. And when the reason for any phenomenon is unknown it is very difficult to predict such a phenomenon...

But however infrequent, and however faint is the lantern about which B. B. Golitsyn wrote, it nevertheless has revealed something. Modern seismology already knows quite a bit about the object of its investigations. For

example, the types of earthquakes have been determined from the nature of movement of the rocks. It has been established what types are characteristic for strong earthquakes and what types are characteristic for weak earthquakes. Different models make possible a more or less reliable representation of what occurs at the focus of an earthquake. We are getting a clearer and clearer idea of how the process of preparation of an "underground storm" transpires in the earth's crust, etc. For those who are interested in these matters in greater depth we suggest reading of a book by A. Gangnus entitled TAYNY ZEMNYKH KATASTROF (Secrets of Terrestrial Catastrophes) (Moscow, "Mysl'," 1977).

All this knowledge will lead to solution of a problem which most researchers consider to be basic: the creation of reliable methods for predicting the time of earthquakes. The necessity for such forecasts is becoming greater and greater because in seismically active zones, as everywhere, the population and production are increasing rapidly. And, naturally, one must know when the event will occur so that people can leave their homes and possibly depart from the danger zone, so that the necessary measures can be taken and the losses insofar as possible can be reduced to a minimum.

Table of Precursors

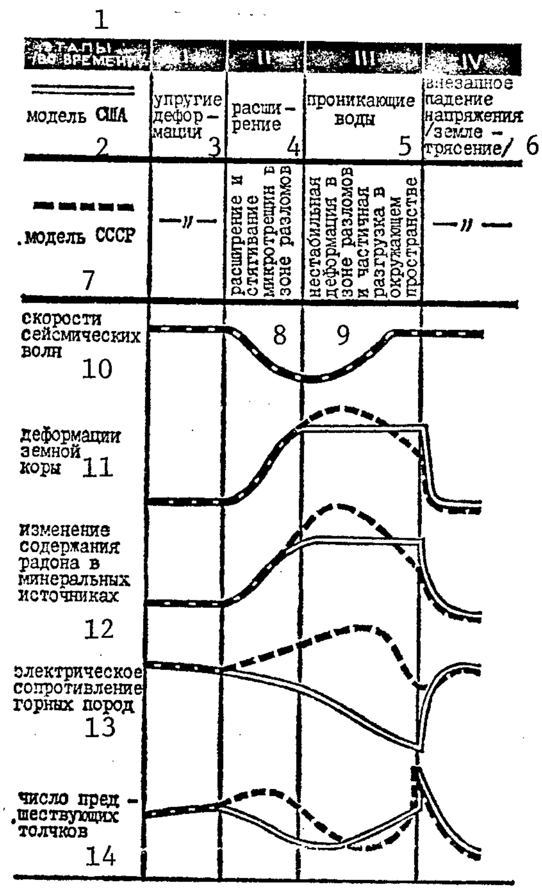
Earthquake precursors	Number of observed cases
Surface deformation	19
Change in surface slope	84
Warning tremors (foreshocks)	73
Displacement of foci	6
Change in ratio of velocities of longitudinal and transverse waves	27
Change in parameters of earth currents	13
Decrease in resistivity	17
Increase in radon content in ground water	9

[The above is a table of "activity" of precursors (according to data from Ye. F. Savarenskiy and I. L. Nersesov).]

However, as we have already mentioned, this is a difficult matter: the true reasons for earthquakes are still not completely known. Scientists must proceed on a most disadvantageous course: they must study earthquakes in progress, study the events and phenomena preceding them and establish a correlation between them and the earthquakes themselves. That is, a search for earthquake precursors must be made.

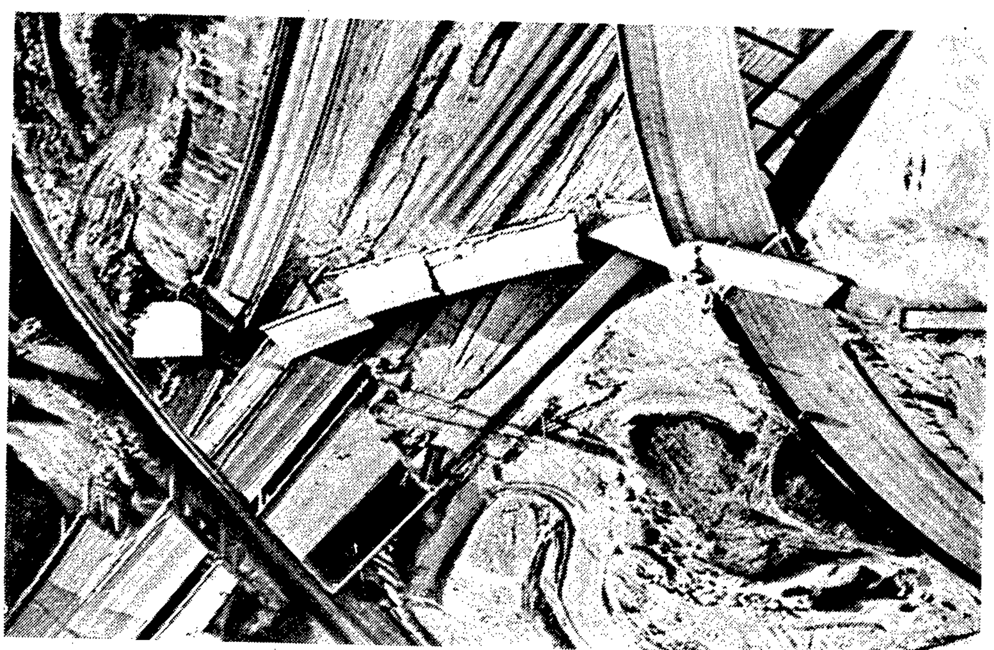
For a long time very little was known about earthquake precursors. Seismology as a science did not exist a hundred years ago. Thirty years ago it had virtually no technical means for creating a forecasting method. Then, after the Ashkhabad earthquake of 1948, Academicians S. I. Vavilov and G. A. Gamburtsev prepared a plan for a search for precursors, but it

was not possible to carry out this plan -- primarily because there were no possibilities for carrying out a great number of geophysical measurements rapidly and with the necessary accuracy. Nevertheless, the basis was then laid for the present-day work of seismologists.



The above figure shows the "preparation process" of an earthquake in the earth's crust as visualized by scientists in the USSR and the United States. Stages I-III precede an earthquake; the boundary between stages III and IV represents the time of onset of an earthquake. It is evident that the ideas in principle are very close, although there are differences in the characteristics of the two stages and some discrepancies in the curves (based on data from Ye. F. Savarenskiy and I. L. Nersesov). 1) Stages in time; 2) US model; 3) elastic deformations; 4) dilatation; 5) penetrating waters; 6) sudden dropoff of stresses (earthquake); 7) USSR model; 8) expansion and contraction of microfissures in fault zone; 9) unstable deformation in fault zone and partial relaxation in surrounding space; 10) velocity of seismic waves; 11) crustal deformations; 12) change in radon content in mineral springs; 13) resistivity of rocks; 14) number of preceding tremors.

California. Faults occur here again and again.



Highway near Los Angeles after another earthquake.

Evidently, the turning point in the search for earthquakes must be considered the Tashkent earthquake of 1966. In actuality, like a lantern, it illuminated many aspects of the problem. It revealed a number of precursors and emphasized the importance, for example, of such a fact that on the eve of an earthquake there is an increase in radon content in ground water. There specialists observed a decrease in the velocity of propagation of seismic waves in the earth's crust and also an appreciable change in the tilt of the earth's surface. All these criteria can be regarded as precursors.

Now specialists know that there are quite a few precursors. For example, on the eve of an earthquake there is a decrease in the resistivity of rocks. An airglow was noted over the future epicenter. There can be a change in water level in wells. Sometimes the approach of an "underground storm" is indicated by the behavior of animals: snakes, for example, creep from their holes and in Japan fishermen very long ago noted that some fish act restless...

Here it must be noted that not one of the precursors in itself gives information which is 100% reliable. And this is understandable. After all, the deep structure of the earth in seismic regions is different and what is true for one region may not hold true for another. But together they can more or less reliably indicate the approach of a catastrophe. This means that there must be a system of observations, constant and precise measurements which are instantaneously transmitted to some center where they can be processed rapidly on electronic computers. The basis for such a system must be a geophysical station outfitted with instrumentation for observations of seismic, acoustic, geochemical, magnetic, electric and other phenomena, etc. Such systems are now being created in different countries, and in our country, to be sure, primarily in the republics of Central Asia. A local system will cover all its regions. This will be a major automated regional seismic system -- BARS (bol'shaya avtomatizirovannaya regional'naya seysmosistema).

But all this, as we mentioned, is for predicting primarily the time of an earthquake. However, a number of scientists feel that it is more important to predict not the time, but the place and intensity of an underground tremor. During recent years more and more high dams have been erected for forming large reservoirs. More and more atomic power stations, chemical combines, petroleum and gas lines and transmission lines are being constructed. The sudden destruction of such objects is fraught with particularly serious consequences. Therefore, Corresponding Member USSR Academy of Sciences V. P. Solonenko feels that it is "vitally important to predict not the precise time when a city, dam, atomic power station and industrial facilities will be destroyed in zones of increased danger, but to construct them in those places and in such a way that they will not be destroyed."

In actuality, we are speaking about seismic regionalization -- the compilation of maps of seismic danger. In our country the methods for seismic regionalization have been developed since the days of the first five-year

plans and the achievements of Soviet scientists along these lines have been adopted as a model in many countries. The recommendations formulated in the Soviet Union have found reflection, for example, in the reports of the seismological missions of UNESCO, which in the 1960's investigated many countries in Asia, South America, Africa, Australia and Europe, and also in a report of the Balkan Seismological Project of UNESCO in the 1970's.

In our day science can already establish the intensity of possible earthquakes and their approximate frequency of recurrence for a specific area having definite seismic criteria. This can be facilitated by the so-called paleoseismological method developed under the direction of V. P. Solonenko at the Institute of the Earth's Crust (Irkutsk). Using this method, a study is made of residual deformations in the earth's crust -- faults or displacements of terrestrial strata. Using these criteria it is possible to determine the epicenters of earthquakes transpiring here during recent millenia, their intensity, frequency of recurrence, and the conclusion can be drawn on this basis that such-and-such can occur here in the future. Such a method, according to the testimony of V. P. Solonenko, makes it possible to shorten the time required for seismological investigations by 10-12 years, and also determine more precisely the seismicity of specific microregions.

The fact is that in the first stages of seismic regionalization underground activity was determined extremely approximately and for only large regions. Let's say, as an example, for Central Asia and the Tien Shan -- up to 9 scale units, and for the Caucasus -- 7-8 scale units. Now work is being done on seismic microregionalization. In this case there is not only a determination of the scale units possible for a particular locality, but also the properties of the ground and other parameters, which now serves as a direct basis for seismic-resistant construction. In this work the paleoseismological method is very useful.

So, what is more important: prediction of the time of an earthquake or its place and intensity? Here there should be no contradiction; both are important because these are different sides of the same problem. It goes without saying that in seismically dangerous regions it is necessary to construct buildings with a corresponding resistance. But still, there is no harm in knowing in advance about an impending earthquake. But then earthquakes can be deceptive: the Gazli region was assumed to be in the 5-scale-unit zone, but the earthquake of the past year was up to 9 scale units!

The search for precursors and the development of methods for predicting the time of an earthquake are now proceeding primarily for those regions where seismic activity is known to be high. In other words, against a background of a long-range forecast (seismic danger maps) scientists are seeking criteria indicating the approach of the time of a calamity so that a short-range forecast can be made on their basis.

In particular, American seismologists in California are now concerned with this problem. There, in the zone of the San Andreas fault, in the past there have already been strong earthquakes and now serious indicators have appeared, especially anomalous shifts of the earth's surface, which indicates the approach of a new strong earthquake. Scientists, naturally, are striving to establish when it will occur and at the same time are actively making use of the prevailing situation in a search for reliable earthquake precursors. Specialists of the USSR, Japan and other countries are taking part in this work. And since we have now touched on the theme of international cooperation, we note that these three countries -- the USSR, the United States and Japan -- are most intensively and with the greatest know-how carrying out work on seismic forecasting and are actively exchanging information and specialists in this field. In seismology international cooperation is of special importance: you recall that earthquakes are rare, but for solution of the prediction problem it is necessary to "collect statistics." This is a big job, tedious and complex work, and it is very reasonable, to be sure, to join the efforts of scientists for implementing this task.

But we will return to California. The situation which has developed there (and it is similar to other places) confirms the point of view of those who feel that earthquakes are not a momentary (on a geological time scale) caprice of nature but part of some powerful planetary processes. Possibly these are the "chips" which fly when the "wood is cut." Deep processes transpire slowly and earthquakes, especially strong ones, take a long time to develop, years, and over a large area, and this means that there is a possibility of recognizing this process, tracing it, and in the long run, make a prediction. The problem is to find precise criteria. Scientists are now at work on this. And progress is being made.

Ye. F. Savarenskiy: The level of research is already making it possible to predict seismic events with a fairly good accuracy. For example, the long-range (for five years) forecasting maps for seismic activity of the Kurile-Kamchatka zone, compiled some time ago at the Institute of Volcanology USSR Academy of Sciences, have proven 75% accurate. Later the Institute of Volcanology, in collaboration with the Institute of Physics of the Earth, made attempts at a routine (several days in advance) forecast and in a number of cases this has proven successful. There are individual cases of precise forecasts abroad as well, in the United States and Japan... However, for practical purposes the reliability of the forecasts is still inadequate, the percentage of false alarms is great and these forecasts are also fraught with unpleasant consequences. Nevertheless, these first attempts show the feasibility of routine forecasting of earthquakes.

5303
CSO: 1870/154

PHYSICS AND MATHEMATICS

UDC: 535.215

NONLINEAR PHOTOELECTRIC EFFECT IN METALS UNDER THE INFLUENCE OF LASER RADIATION

Moscow USPEKHI FIZICHESKIKH NAUK in Russian Vol 122, No 2, Jun 77 pp 185-222

[Article by S. I. Anisimov, V. A. Benderskiy, and D. Farkash]

[Text] 1. Introduction

Extensive utilization of lasers in various areas of experimental physics, which began in the 1960s, opened up new possibilities for solving a great many fundamental problems. Suffice it to mention investigation of multiple-photon processes in atoms and molecules [1], new ideas in the field of controlled thermonuclear synthesis [2-4], laser methods of isotope separation [5, 6], and laser methods of research in solid-state physics [7-9]. Of considerable interest among the latter is study of multiple-photon processes in solids, and in particular research on nonlinear photoelectric effect. This article presents a review of the contemporary state of research in this area.

First estimates of the effectiveness of electron emission from metal with absorption of two photons were published long before the invention of the laser [10]. The opportunity for experimental observation of this effect, however, did not appear until the development of fairly high-power lasers. It was elucidated thereby that in addition to high light intensity, essential for observation of two-photon emission is a suitable experiment method which enables one to eliminate emission currents caused by other mechanisms. The first report [11] on observation of a photocurrent proportional to the square of light intensity was published in 1964. The method employed in this study did not offer the possibility of observing processes of a higher order of intensity. The method suggested in [12], which made it possible to investigate photoemission with absorption of three and more photons, proved to be considerably more effective. The results of these experiments were in satisfactory agreement with the first theoretical computations of the probability of multiple-photon photoeffect [13-15]. Somewhat later measurements of the absolute values of photon yield for a two- and three-photon process [16] also confirmed the qualitative correctness of the theoretical calculations.

The above-enumerated studies are typical of the first stage of investigation of the multiple-photon photoeffect. The principal task at this stage was observation of the effect, and the question of detailed investigation of such important characteristics of the phenomenon as angular and energy distribution of emitted electrons, temporal, spectral, threshold and polarization relationships of the photocurrent was not actually raised. Comparison of theoretical and experimental results boiled down essentially to comparison of lux-ampere characteristics and absolute photocurrent values. A fairly detailed review of research pertaining to this stage can be found in [9, 17, 18].

In this article principal attention is focused on research conducted in recent years and containing in particular an analysis of the above-enumerated emission current characteristics. Although such research is of obvious interest and, as is indicated by studies on conventional, single-photon photoeffect [19], enables one to obtain important information on the structure, electron spectrum and properties of the surface layers of solids, corresponding multiple-photon experiments prove to be fairly complex. One of the obstacles in performing quantitative experiments is the low photocurrent value and the related necessity of utilizing high-power laser pulses. Heating of the photocathode, which is practically inevitable under such conditions, leads to the occurrence of thermionic emission, which complicates investigation of the fine details of photoelectric effect. As analysis indicates, thermal effects are an obstacle for observation of photoemission of a fairly high order of magnitude. Competition between the processes of photoemission and thermoemission was first discussed in [20]. A sufficiently complete analysis of this question, however, was conducted at a later time [21, 22] and was not reflected in published reviews. The conduct and results of experiments on multiple-photon emission in a vacuum together with a qualitative analysis of the conditions of observation of photoeffect on the background of thermionic emission are described in Section 2 of this article.

One very interesting area of investigation which has developed rapidly in recent years is the study of photoeffect in extremely strong electrical fields. Theory predicts in this instance a relationship between emission current and field intensity, characteristic of field emission [15, 23, 24]. Experimental study of this problem requires elimination of thermal effects, which can be achieved to a substantial degree by shifting to ultrashort laser pulses. The first experiments of this kind, performed with the employment of a train of picosecond pulses, are described in [25, 26]. These and subsequent investigations studied in detail the lux-ampere characteristic curve with incident beam intensities up to tens of Gw/cm^2. There were discovered significant deviations from the standard power law observed in the region of moderate intensities. The problem of interpretation of these deviations proves to be fairly complex; we shall discuss it in Section 5.

Another interesting question which has also been practically ignored in the survey literature is investigation of multiple-photon photoeffect at the

metal-electrolyte boundary. In working with electrolytes there arises the important possibility of altering within broad limits the work function, leaving other experiment parameters unchanged. This creates convenient conditions for verifying existing theoretical concepts on the mechanisms of photoemission. Section 3 of this review contains a detailed description of experiments on multiple-photon emission into electrolyte and analysis of experimental results.

In this article we shall not discuss a number of important aspects, inclusion of which would make it impossible to present a sufficiently detailed survey. They include first and foremost the question of the statistical characteristics of nonlinear photoemission and the various aspects of practical employment of nonlinear photoeffect. Some data on these questions is contained in survey article [9].

2. Experimental Investigation of Nonlinear Photoemission From Metals into a Vacuum Under the Effect of Nanosecond Laser Pulses

In the first experiments, performed by various authors in 1963-1965 [27-30], investigators observed emission of electrons from the surface of metal targets under the effect of laser pulses operating in free generation mode, when light pulses had a duration of ~1 msec with an average power of ~10 kw and consisted of a set of random, irregular peaks. The occurrence of emission was explained as due to heating of the target with light, while due to the "spike nature" of the pulses, quantitative results were not obtained. Quantitative measurements required pulses with accurately-measurable temporal and spectral characteristics controlled by distribution of intensity of radiation through the area of the light beam and regulated by peak intensity. Such pulses, frequently called giant pulses, can be obtained with lasers operating in Q modulation mode. Pulse shape is close to Gaussian with a halfwidth of $\sim 10^{-8}$ sec, while peak power comprises 10^8 w/cm^2 in the typical case. Ruby laser pulses with these characteristics were utilized in the first experiments performed by Ready [31] who, on the basis of measurements of current from the surface of tungsten targets, concluded that the effect was of a thermal emission nature. Somewhat later Knecht [32], working under very similar experimental conditions, obtained results which could not be explained exclusively with target heating.

The results of theoretical investigation of multiple-photon photoeffect exerted considerable influence on subsequent systematic measurements of electron emission. Theoretical analysis made it possible to establish conditions under which multiple-photon photoemission can be reliably identified experimentally. We shall discuss first of all the characteristic features distinguishing photoemission from thermionic emission.

a) In contrast to thermocurrent, a photocurrent is proportional to the n degree of light intensity

$$j_n = \eta_n I^n, \qquad (1)$$

where η_n is the probability of n-photon photoeffect. The order of magnitude of photoeffect n can be determined

from experimental data and compared with theoretical value

$$n = \left\langle 1 + \frac{A}{\hbar\omega} \right\rangle,$$

where A is the work function from the metal and diagonal parentheses $\langle x \rangle$ signify the whole part of number x. Concurrence of the expected value of n with that obtained experimentally serves as an important evidence of the photoemissive nature of the measured current.

b) Since with the photoelectric effect the discharge of electrons when photons strike the cathode takes place noninertially, there is no current pulse delay relative to the laser pulse. As a consequence of nonlinearity of the lux-ampere characteristic curve, the photocurrent pulse should be shorter than the laser pulse. For example, with Gaussian shape of the latter, photocurrent pulse duration t_j is related to laser pulse duration t_0 by the ratio

$$t_j = \frac{t_0}{\sqrt{n}}.$$

In the case of thermal emission, the shape of the current pulse is determined by change in target temperature on a time axis. The current pulse maximum is delayed relative to the laser pulse maximum, its duration exceeds t_0, while the shape of the dropoff is determined by the thermal-physical properties of the target material (see [8, 30]).

c) It is a well-known fact that surface photoelectric effect is a typical vector phenomenon. Current quantity is determined by the wave electrical field component normal to the surface, and is sharply dependent on light angles of incidence and polarization. With multiple-photon photoemission this relationship is very pronounced:

$$j_n \sim \mathscr{E}_z^{2n} \sim \sin^{2n}\theta \sin^{2n}\varphi,$$

where θ is the angle of incidence and ϕ is the angle of polarization relative to the plane of incidence. With interior photoeffect, the relationship between photocurrent and angles of incidence and polarization is connected with the n degree of power absorbed in the metal, although it differs somewhat from it as well. (see below, Section 5). On the other hand, thermionic emission current is determined entirely by the temperature of the metal surface, which in turn is determined by absorbed power. Thus measurements of the angular and polarization relations of emission current enable one to distinguish multiple-photon surface photoeffect from interior, and the latter from thermal emission.

d) The energy distribution of emitted electrons during photoeffect differs sharply from the Maxwellian distribution which occurs during thermal emission. In the former instance the distribution maximum is close to the maximum energy of emitted electrons

$$E_{max} = n\hbar\omega - A$$

and is not dependent on light intensity and time, while in the latter instance it is proportional to the temperature of the surface and changes with time.

The above-enumerated differences in properties of multiple-photon and thermal emission currents provide a basic possibility of observing nonlinear photoeffect on the background of thermal emission. The decrease in thermal emission background requisite for quantitative experiments can be obtained by various means. We shall discuss the most frequently utilized methods.

1) Thermocurrent increases can be obtained by decreasing laser beam intensity. In this case, however, the photocurrent, proportional to the n degree of intensity, also proves to be extremely small, which makes its observation difficult. For all practical purposes one can investigate only two-photon photoeffect with this method, whereby a one-photon process makes a certain contribution to the experimentally observed current, occurring due to the temperature tail in the Fermi distribution [11]. We shall discuss this question in somewhat greater detail. The different contributions to emission current are shown in Figure 1. The following relation occurs for one-photon emission in a vacuum when $kT \ll A-\hbar\omega$:

$$j_1 = 2\eta_1 \left(\frac{kT}{A-\hbar\omega}\right)^2 \exp\left(\frac{\hbar\omega - A}{kT}\right), \qquad (2)$$

where η_1 -- one-photon process photon yield. The temperature of the target surface, with time-constant laser intensity, does not exceed the value

$$T_{\max} = bI\sqrt{t_0}, \qquad b = \frac{1-R}{\sqrt{\pi\chi c\rho}}, \qquad (3)$$

where c, χ and ρ are heat capacity, heat conductivity and metal density respectively, and R is the coefficient of surface reflection. Figure 2 contains lux-ampere characteristic curves, calculated with formulas (2) and (3), of a one-photon current connected with a Fermi distribution tail, with different values of $A-\hbar\omega$. Calculation was performed with typical values for metals $\eta_1=2\cdot10^{-4}$ a/w, b=0.3 degr$\cdot$cm^2/w$\cdot$sec$^{1/2}$, and t_0=10 nsec. It is easy to see that contribution j_1 drops off exponentially with an increase in $A-\hbar\omega$, while the lux-ampere characteristic curve is ultralinear due to temperature increase. Further, calculating two-photon emission current and formulating ratio j_2/j_1, we see that the region of intensities in which $j_2>j_1$ is limited both above and below. The size of the region decreases with a decrease of $A-\hbar\omega$ and when $A-\hbar\omega \lesssim 0.3$ ev, observation of two-photon photoeffect becomes practically impossible. Rigorous calculation of photocurrents of higher orders of magnitude, taking into account target heating, which we shall perform in Section 5, shows that even under optimal conditions observation of photocurrents with n>6 becomes practically impossible due to thermal effects.

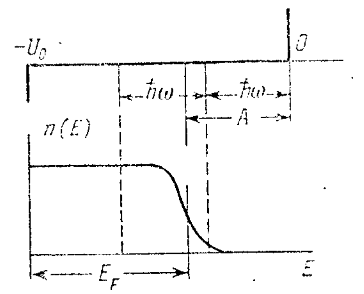


Figure 1. Electron Emission, Metal With Absorption of One and Two Photons

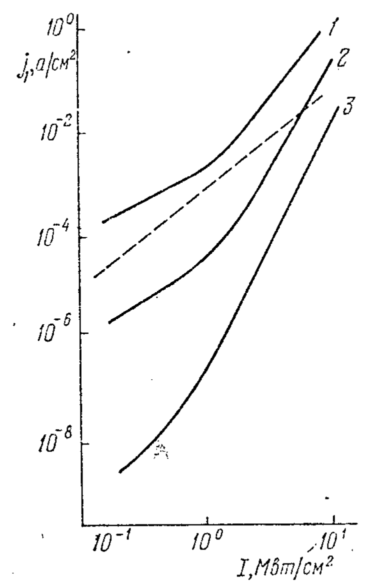


Figure 2. Lux-Ampere Characteristic Curves of One-Photon Photoeffect With Different Values of $A-\hbar\omega$ (ev): 1 -- 0.42 ev, 2 -- 0.32 ev, 3 -- 0.22 ev. The dashed line indicates the characteristic curve of two-photon photoeffect

2) Thermocurrent can be decreased by reducing power absorbed on the cathode by utilization of angles of incidence close to 90°. In this case the reflectivity of a flat metal surface is very high, and can reach 98-99% even for such metals as gold and silver. With this method one can substantially reduce heating of the cathode, at the same time providing the possibility of observation of nonlinear surface photoeffect connected with the wave electrical field component normal to the metal surface.

3) With a given laser intensity, target temperature can be reduced by decreasing laser pulse duration. This possibility, suggested in [20], for all practical purposes reduces to a change from normal giant pulses of a duration

in the order of 10 nsec to ultrashort pulses generated in self-synchronization mode and possessing a duration in the order of 10 psec. With such short durations of irradiation it is possible to avoid appreciable heating of the target even in the case of comparatively high laser intensities. A shortened pulse duration leads, however, to change in the character of heating of the metal as a consequence of disruption of the equilibrium between electrons and lattice, which in turn affects the magnitude of the thermionic emission current [21] (see below, Section 4).

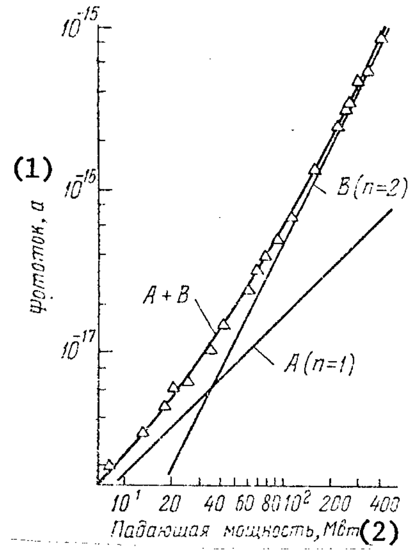


Figure 3. Lux-Ampere Characteristic Curve [11]

Key:
1. Photocurrent
2. Decreasing power, Mw

Experimental setups for investigating multiple-photon emission under the effect of nanosecond and picosecond pulses are analogous in structure and consist of the following basic components (Figure 5):

a) laser;

b) devices to change intensity, polarize and focus the laser beam: light filters, polarizers, prism;

c) devices for measuring energy intensity, duration and spatial distribution in the laser beam: high-speed linear photocells, calorimeter, high-speed motion picture camera, and memory oscilloscopes;

d) vacuum chamber with metal target, collecting electrode (sometimes replaced by an electron multiplier) and a system for analyzing the energy distribution of emitted electrons;

e) instruments for recording photocurrent pulses: wideband amplifiers, pulse voltmeters and high-speed oscilloscopes with a bandwidth (when operating in the nanosecond band) of approximately 100 MHz.

We shall begin presentation of experimental results with the first investigation [11], which is intermediate between the above-mentioned preliminary measurements [27-31] and subsequent systematic experiments with nanosecond pulses. In [11] investigators examined emission from vaporized-on sodium layers (A=1.95 ev) under the effect of gallium arsenide semiconductor laser pulses with λ=8,400 Å, with a duration of approximately 3 microseconds and a repetition frequency of 2.2 kHz. Since the energy of a photon is equal to 1.48 ev, the appearance of two-photon photoemission was expected in the experiment. With focusing on the target surface, a radiation flux density of up 10 kw/cm^2 was created. Figure 3 contains the measured lux-ampere characteristic curve. It can be presented in the form of a sum of the linear (A) and quadratic (B) components of the photocurrent. The former was determined by one-photon photoemission from the energy distribution tail. The experimentally measured photocathode temperature increase did not exceed 2°C, which indicated the absence of thermionic current. In conformity with the above, the contribution of two-photon emission increased with an increase in light intensity. The measured current values in this experiment were extremely small: from 6 x 10^{-18} to 3 x 10^{-16} a.

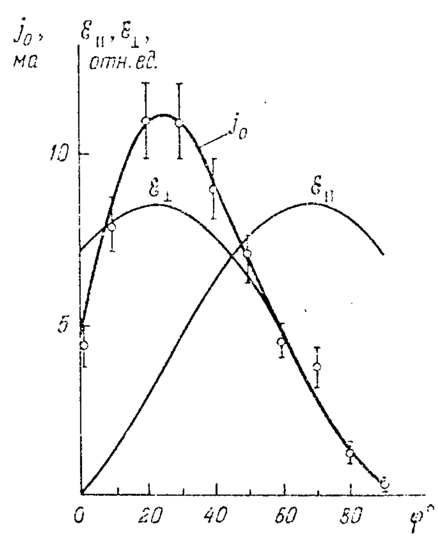


Figure 4. Relationship Between Photocurrent and Radiation Polarization

The measured value of two-photon current, with an accuracy to a factor of 3, was found in conformity with the calculations of Smith [13], whose results, however, were subsequently corrected [33]. We should also note that the authors of [11] initially ascribed their figures to surface photoeffect, although photocurrent was observed with normal light incidence onto the photocathode, when surface photoeffect should not have been present, for

obvious reasons. In a later study by those same authors [34], two-photon photoemission from sodium under the effect of helium-neon laser radiation and a gallium arsenide laser was viewed as interior effect. In [35] investigators were able to measure two-photon emission in the absence of a thermal background. The experimental value of the photon yield of two-photon photoeffect, however, proved to be larger by three orders of magnitude than that predicted by theory [36].

Table I

Лазер (1)	Длина волны, мкм (2)	Энергия фотонов, эв (3)	Длительность импульса, нсек (4)	Мощность, Мвт (5)
Рубин (6)	0,6943	1,78	25	10—100
Рубин с удвоением частоты (7)	0,3471	3,57	25	10—50
Неодимовое стекло (8)	1,06	1,17	40	10—100
Неодимовое стекло с удвоением частоты (9)	0,53	2,34	40	10—50

Key:
1. Laser
2. Wavelength, micron
3. Photon energy, ev
4. Pulse duration, nsec
5. Power, Mw
6. Ruby
7. Ruby with frequency doubling
8. Neodymium glass
9. Neodymium glass with frequency doubling

We shall now discuss the results obtained with laser pulses of nanosecond duration. Ruby and neodymium glass lasers were employed in the experiments described below. The pulses were usually of Gaussian shape in time and frequency, with a duration in the order of 10 nsec. In a number of instances frequency doubling was employed, with the aid of KDP [expansion unknown] crystals. Pulse characteristics are contained in Table I.

a) Polarization Relationship of Photocurrent

In experiments [12] investigators employed a ruby laser and a silver photocathode with work function of 4.7 ev. The laser beam, passing through a Glan-Thompson prism, struck the cathode surface at an angle of 87°. By turning the prism, investigators obtained a continuous change in wave electric field components parallel and perpendicular to the surface. Figure 4 contains measurement results. One can see that only the field component perpendicular to the cathode surface plays a role in the process of emission, while the emission current reveals a pronounced polarization relationship. Current pulse duration proves to be less than the laser pulse duration, which indicates the multiple-photon character of emission.

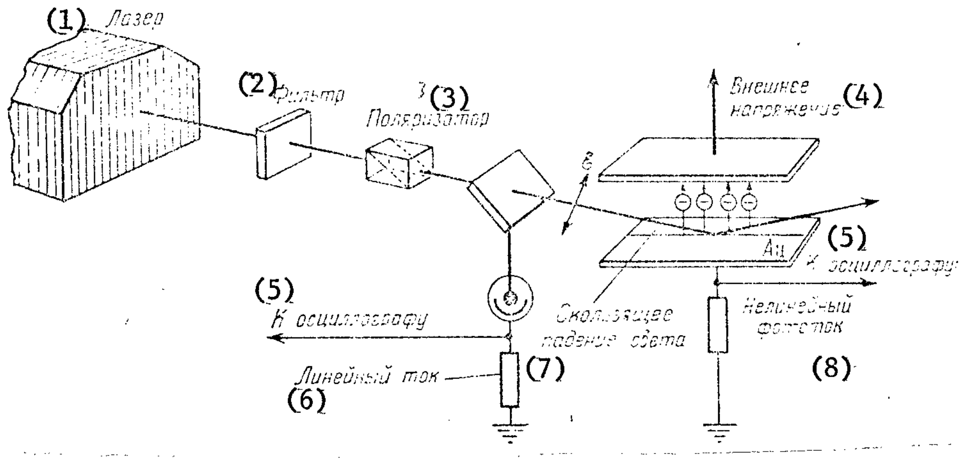


Figure 5. Diagram of Experiment to Observe Nonlinear Photoemission Into a Vacuum

Key:

1. Laser
2. Filter
3. Polarizer
4. External voltage
5. To oscilloscope
6. Linear current
7. Glancing light incidence
8. Nonlinear photocurrent

It is interesting to note that one-photon photoeffect for silver with the same maximum electron energy (approximately 0.5 ev) was interpreted in [37] as interior, while three-photon, according to [12], is purely surface.

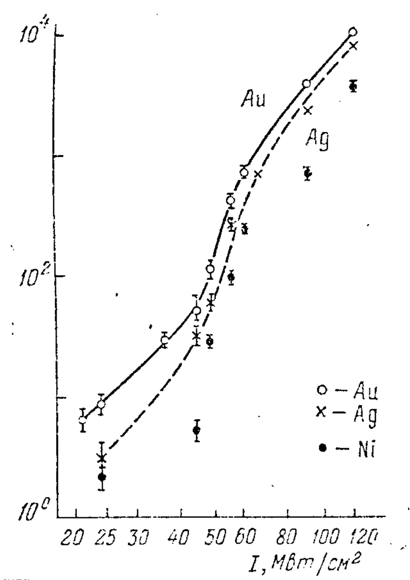


Figure 6. Relationship Between Photocurrent and Radiation Intensity [12]

b) Relationship Between Photocurrent and Intensity of Radiation

Theory of nonlinear photoeffect gives for emission current a relationship with intensity of type (1), valid in the case of not excessively high intensities. An experimental investigation of this relationship was conducted almost simultaneously in two studies -- [38] and [39]. Later more detailed measurements were performed in [34, 40].

In [38] an unfocused ruby laser beam was aimed at a cathode almost parallel to the surface. Intensity in the beam varied from 24 to 120 Mw/cm^2, which corresponded to a radiation flux density on the target from 2 to 10 Mw/cm^2. We employed cathodes of gold, silver and nickel, with work function of 4.8 ev, 4.8 ev, and 5.1 ev respectively. The photoeffect order of magnitude was equal to three. Figure 6 contains the measurement results, from which it is evident that relationship $j_3 \sim I^3$ occurs for gold and silver in an intensity interval from 2 to 5 Mw/cm^2. With an intensity increase the relationship became more pronounced, which could be connected with heating of the target. For a nickel cathode we observed a large spread of experimental data, connected with the inferior optical and thermophysical properties of nickel.

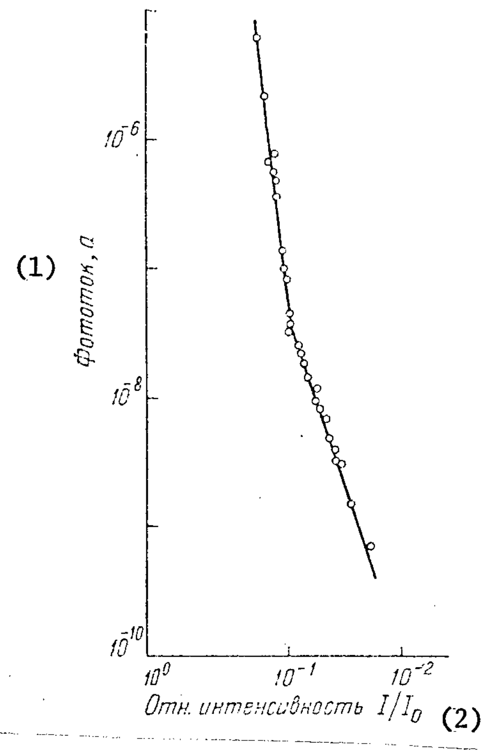


Figure 7. Lux-ampere Characteristic Curve in the Region of Transition from Photoemission to Thermoemission (I_0=14 Mw/cm^2)

Key:
1. Photocurrent
2. Relative intensity

In [39] a ruby laser with an energy of 1 J and pulse duration of 40 nsec was used. The unfocused beam struck at an angle of 60° a cathode in the form of a thin layer of gold on a steel backing. Three-photon emission was observed at intensities less than 1 Mw/cm^2 ; a further increase in intensity led to rapid current increase due to thermal effects (Figure 7). A lower intensity value than in [38] at which thermal emission "cut in" is due to the fact that in [39] the angle of incidence was smaller, while absorbed power and cathode temperature were greater than in [38]. In [39] constant η_3 in the relationship $j_3=\eta_3 I^3$ was measured. For this constant the following value was obtained: $\eta_3=1.0 \cdot 10^{-13}$ $a \cdot cm^4/Mw^3$. For quantum yield, defined as the number of photoelectrons per photon, one obtains from this the value $1.8 \times 10^{-25} I^2$.

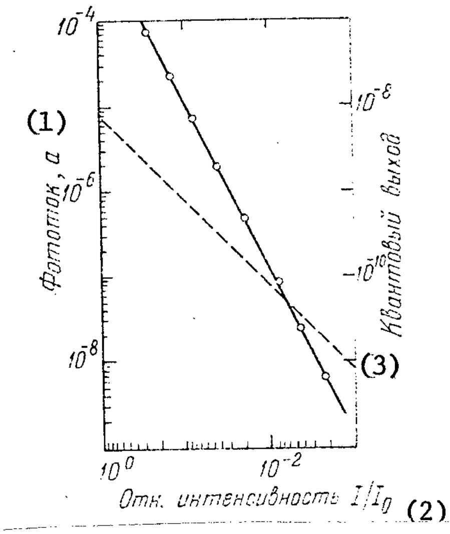


Figure 8. Quantum Yield of Two-Photon Photoeffect ($I_0 \approx 1$ Mw/cm^2)

Key:
1. Photocurrent
2. Relative intensity
3. Quantum yield

In the second part of [39], the authors investigated two-photon photoeffect on that same target under the effect of the second harmonic of a ruby laser (A=4.8 ev, $2\hbar\omega=3.57$ ev). At intensities less than 1 Mw/cm^2, the observed current was entirely due to two-photon photoeffect (Figure 8). The measured value of the constant in an expression for emission current $j_2=\eta_2 I^2$ proved equal to 2.35×10^{-15} $a \cdot cm^2/w^2$. Figure 8 also shows the relationship between photoeffect quantum yield and intensity.

In a later study [16] those same authors presented the results of a detailed investigation of nonlinear photoemission from the surface of various metals, including stainless steel (A=5.0 ev). They expected the appearance of photocurrents with n=3-4 for a ruby laser and n=5 for a neodymium laser. Instead of this, in both instances they observed a poorly reproducible relationship of type (1) with $n \approx 7$, evidently caused by thermal effects. For the second harmonic of a ruby laser they observed the

theoretically expected two-photon emission in an intensity interval from 1 kw/cm^2 to 1 Mw/cm^2.

Thus on the basis of analysis of the above-enumerated studies one can conclude that with a nanosecond laser pulse duration nonlinear photoeffect can be observed only within a limited radiation intensity interval approximately from 10 kw/cm^2 to 1-5 Mw/cm^2, whereby observation of photocurrents where the order of magnitude is greater than the third, proves impossible due to thermal effects, the principal one of which is emission of low orders of magnitude due to transitions from the energy distribution tail. As we shall see below (see Section 4), the interval available to observation can be broadened by transitioning to picosecond pulses.

c) Emission Current Time Characteristic Curves

Corresponding measurements were performed in [40]. A ruby laser pulse of Gaussian shape with a halfwidth of 20 nsec was beamed at an angle of 82° to a gold cathode. The authors measured the time interval between laser pulse maximum and emission current maximum as a function of laser intensity. Figure 9 contains the measurement results. One can see that with intensities not exceeding 4 Mw/cm^2, there is no lag, which indicates the photoelectric nature of the current pulse. At intensities exceeding 4 Mw/cm^2 an emission current lag is observed, which is in conformity with the lux-ampere characteristic curve measurements described above.

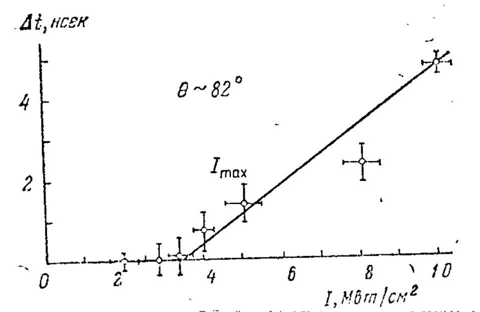


Figure 9. Emission Current Lag Relative to Laser Pulse

Measurements of emission current pulse halfwidth constitute an additional confirmation of the described results. In [16], with a laser pulse halfwidth of 40 nsec, the current pulse halfwidth was 22 nsec, which is in precise conformity with three-photon photoeffect. In [40] the current pulse halfwidth was measured in relation to light intensity (Figure 10). As was expected, at intensities of I<4 Mw/cm^2 the current pulse halfwidth was 20 $\sqrt{3}$ =11 nsec; at higher intensities this value increased, indicating the dominant role of thermal emission.

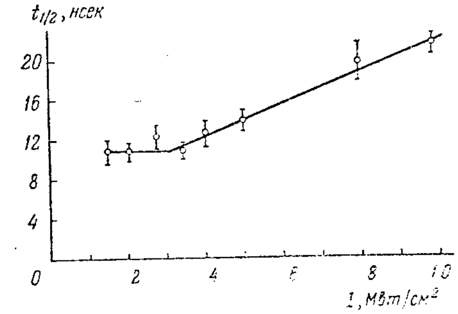


Figure 10. Relationship Between Current Pulse Halfwidth and Laser Intensity. Laser pulse halfwidth=20 nsec

d) Energy Distribution of Emitted Electrons

An experimental investigation of energy distribution of electrons was performed in [16]. With a ruby laser beamed on targets of iron and gold (Figure 11), the energy distribution maximum lies at zero energy, which corresponds to thermionic emission. For the second harmonic of that same laser, the emitted electron distribution function has a maximum lying at an energy of approximately 1 ev, which attests to the multiple-photon character of emission. We shall note that for comparison of experiment with theory it would be of undoubted interest to measure the relationship between photocurrent and electron energy. This relationship can be determined in principle from an analysis of the energy distribution of emitted electrons. For practical purposes, however, accuracy of measurements in [16] is sufficient only to distinguish photocurrent from current caused by thermal effects.

Also of significant interest are measurements of the relationship between photocurrent and frequency of radiation. An obstacle to such measurements is the fact that measurements of photocurrents are usually performed at fixed radiation frequencies of a given laser. Performance of spectral measurements of multiple-photon emission into a vacuum encounters substantial methodological difficulties and has not been undertaken up to the present time. A number of difficulties in experimentally determining the relationship between photocurrent on the one hand and frequency and energy of emitted electrons on the other can be surmounted by studying nonlinear photoemission into electrolyte solutions. In this case there is no need for spectral measurements, since it is possible to change work function by measuring photocathode potential. The results of these experiments are examined in the following section.

3. Experimental Investigation of Nonlinear Photoemission From Metals Into Electrolyte Solutions

The difference between photoemission from metals into an electrolyte solution and emission into a vacuum involves in the first place a drop in

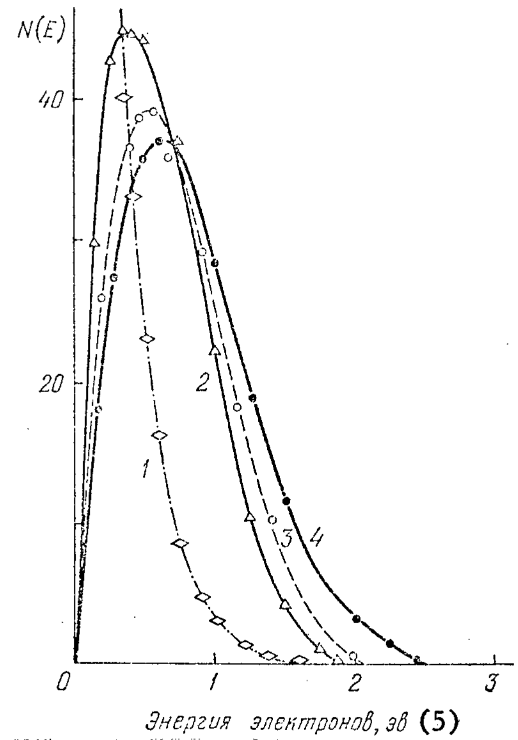


Figure 11. Energy Distribution of Emitted Electrons

Key:

1. Thermal emission
2. Steel, second harmonic of ruby, photoemission
3. Silver, second harmonic of ruby, photoemission
4. Gold, second harmonic of ruby, photoemission
5. Electron energy, ev

---

potential in an electric double layer on an interface, the thickness of which is less than the wavelength of the emitted electrons, and in the second place, Coulomb screening in the solution, which attenuates the force of the electrical image. Due to the first difference, the photoelectric threshold becomes a linear function of potential

$$\hbar\omega = \hbar\omega_0 - e\varphi,$$

where $\hbar\omega_0$ is work function from metal into the electrolyte in the absence of charge on the interface, ϕ -- photocathode potential measured from the point of zero charge. Due to the presence of Coulomb shielding, the relationship between photocurrent and maximum energy of emitted electrons is described by the "5/2 law," not by the conventional Fowler's law. These features have been examined in detail in the case of one-photon photoeffect.

Photoemission from mercury into electrolyte under the effect of ruby and neodymium laser pulses was first observed by Korshunov et al [42]. It was demonstrated that the current generated under the effect of ruby laser peak pulses is related to the square of light intensity, which corresponds to theoretically expected two-photon photoemission. The volt-ampere characteristic curve of this current was described by the "5/2 law" within the limits of accuracy of measurements. This verified the theory-predicted relationship between a nonlinear photocurrent with n=2 and the energy of emitted electrons, which was not verified, as is noted at the end of the preceding section, in experiments on multiple-photon photoemission into a vacuum.

Subsequent more detailed investigations of two-photon photoemission [43-45] were performed with utilization of nanosecond laser pulses. Figure 12 contains a block diagram of the setup. A laser pulse is beamed through a system of calibrated attenuators, mirrors and light filters onto the cathode of an electrochemical cell. A portion of the light beam, separated by quartz plates, is fed to a microcalorimeter, which measures laser pulse energy, and a high-speed photocell, to monitor its amplitude and shape. The signal at the electrochemical cell output is amplified by a wideband amplifier and recorded by a memory oscilloscope. Due to the large capacity of the electrochemical cell, not current but emitted charge is measured.

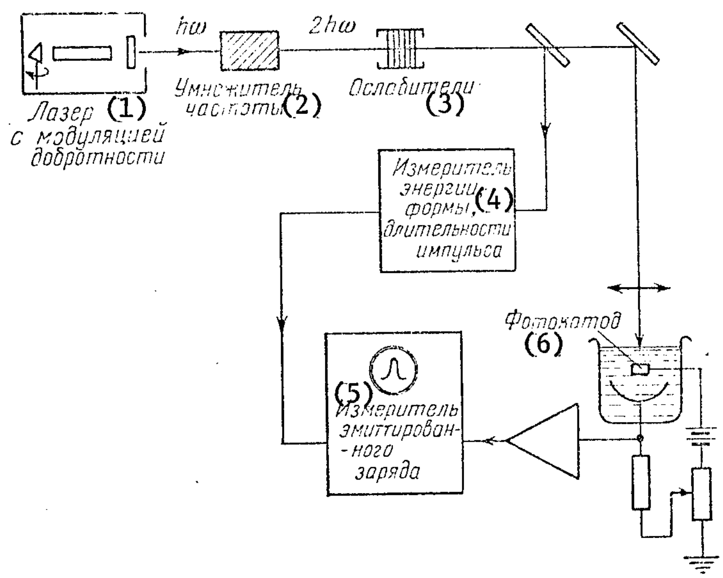


Figure 12. Diagram of Experiment on Observing Nonlinear Photoemission Into Electrolyte

Key:

1. Laser with Q modulation
2. Frequency multiplier
3. Attenuators
4. Pulse energy, shape, and duration measuring unit
5. Emitted charge measuring unit
6. Photocathode

In addition to interfering currents connected with the thermal effect examined in the preceding section, heating currents are generated in the electrochemical cell with intensive illumination. A full charge produced by these currents is equal, however, to zero under the condition that the recording time is greater than the thermal relaxation time. If this condition is met, the measured signal is proportional to the emitted charge. On the other hand, measurement of the heating signal makes it possible directly to determine electrode temperature.

We should note that the sensitivity of the recording equipment in charge measurement mode does not permit reducing laser pulse duration, since when $t_0 \sim 10^{-8}$ sec, measured multiple-photon photoemission signals comprise 10^{-5}-10^{-3} V, and in order to extract these signals it is necessary to reduce the passband of the measuring system which, just as the presence of a heating signal, forces one to refrain from measuring signal kinetics.

Since the conditions of measuring multiple-photon photoemission into a vacuum and into electrolyte, as is clear from the above, differ (we shall also point out that in the latter case one cannot measure energy distribution of the emitted electrons), in order to identify it one employs other characteristics in comparison with those enumerated at the beginning of Section 2. They include the following:

a) the exponential relationship between emitted charge and light intensity;

b) realization of the "5/2 law" at all light intensities, which is equivalent to independence of emitted electron energy distribution from light intensity;

c) concurrence of two- and one-photon photoemission threshold (to which identical volt-ampere characteristic curve extrapolation potentials correspond), when excitation is effected with laser pulses with photon energies $\hbar\omega$ and $2\hbar\omega$;

d) equality of difference in photon energy extrapolation potentials with change in the photoeffect order of magnitude by 1.

The last two criteria follow directly from the relationship between n-photon photocurrent and maximum energy of emitted electrons:

$$j_1 \sim (\hbar\omega - \hbar\omega_0 + e\varphi)^{5/2}, \quad e\varphi_{01} = \hbar(\omega_0 - \omega), \tag{4}$$

$$j_2 \sim (2\hbar\omega - \hbar\omega_0 + e\varphi)^{5/2}, \quad e\varphi_{02} = \hbar(\omega_0 - 2\omega). \tag{5}$$

Table II contains values of extrapolation potentials ϕ_{0n} for two- and one-photon photoemission under the effect of the first and second harmonics of a ruby and neodymium laser.

Table II

Лазер (1)	(2) Энергия кванта, эв	φ_{01}, в *)	φ_{02}, в *)
Рубин (3)	1,78	—1,73	—0,06
Вторая гармоника рубина (4)	3,57	+0,06	—
Неодим (5)	1,17	—2,34	—1,17
Вторая гармоника неодима (6)	2,34	—1,17	—1,17

*) Значения потенциалов даны относительно потенциала насыщенного каломельного электрода (НКЭ). (7)

Key:
1. Laser
2. Quantum energy, ev
3. Ruby
4. Second harmonic of ruby
5. Neodymium
6. Second harmonic of neodymium
7. Values of potentials are given relative to the potential of a saturated calomel electrode (NKE)

It is evident from the table that in the effective region of mercury electrode potentials (+0.1 – -2.0 V NKE) one can observe both one- and two-photon photoemission. In addition, with a change in electrode potential one should observe the above-indicated change in photoeffect order of magnitude: a transition n=2 to n=1 -- under the effect of ruby laser first harmonic pulses and neodymium laser second harmonic pulses, which makes it possible directly to measure the ratio of photoeffect efficiency with n=2 and n=3; eliminating change in j_2/j_1 both by differing conditions of absorption of light of different wavelengths in the metal and differences in the characteristics of pulses of different light sources, utilization of which is mandatory when measuring photoemission into a vacuum.

We shall now present experimental results. A square relationship between emitted charge and intensity of ruby laser nanosecond pulses (duration 30 nsec) was observed for mercury, lead, silver and copper up to 3 Mw/cm^2 in an incident beam with 45° angles of incidence for solid electrodes and from 60° to 90° for mercury. The corresponding relations are shown in Figure 13, taken from [43]. Obtained value n is equal to 2±0.2. Figures 14 and 15 show Q(I) relations for one- and two-photon photoemission from mercury and lead under the effect of the second and first harmonics of a ruby laser respectively [45]. Elevation of temperature of the metal when I=3 Mw/cm^2, estimated on the basis of magnitude of heating signal, does not exceed 50°, which is in conformity with calculations. The thermal emission and photoemission current from the energy distribution "tail" is 4-5 orders of magnitude below two-photon photoemission current (see figures 2 and 3).

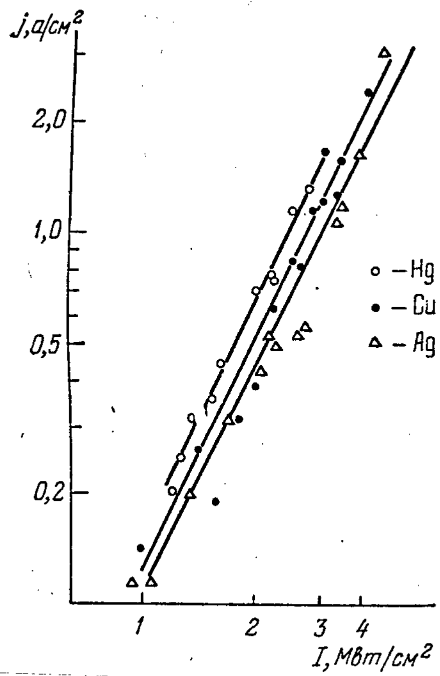
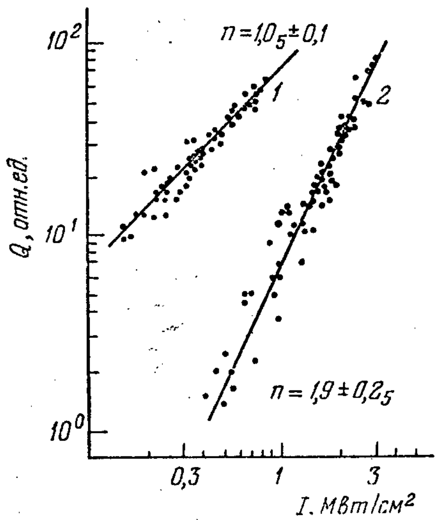


Figure 13. Two-Photon Emission From Mercury, Silver, and Copper



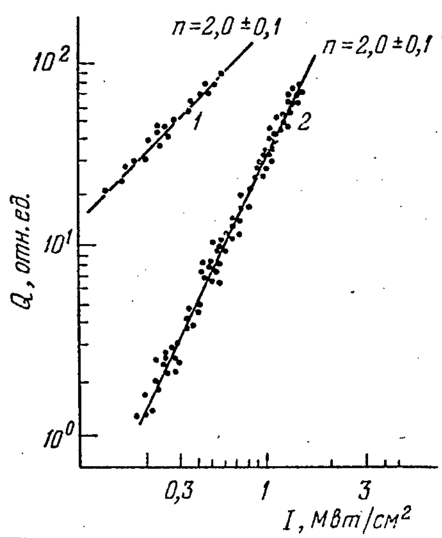


Figure 14. Lux-Ampere Relations of One-Photon (1) and Two-Photon (2) Emission From Lead Into Electrolyte

Figure 15. Lux-Ampere Relations of One-Photon (1) and Two-Photon (2) Emission From Mercury Into Electrolyte

An appreciable contribution of thermal effects, manifested in a sharp steepening of the slope of the lux-ampere characteristic curve, is usually observed at light intensities exceeding 5 Mw/cm^2. A square-law current variation was observed for a mercury electrode in [46]. In comparing the indicated value I_{max}=5 Mw/cm^2 with that given in the preceding section (~1 Mw/cm^2), one should bear in mind that in these cases the photoeffect order of magnitude is different (n=2 with photoemission into electrolyte and n=3 with photoemission into a vacuum), and since the probability of photoemission with identical values of I decreases by several orders of magnitude with an increase in n by 1, the value of maximum intensity at which current is caused by photoeffect increases during transition from n=3 to n=2.

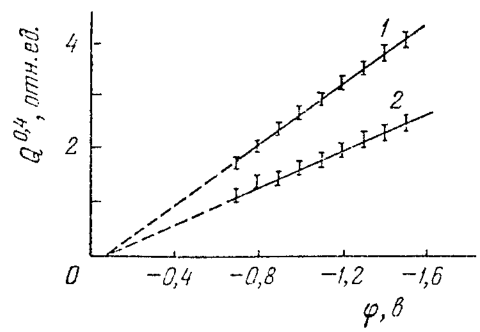


Figure 16. Volt-Ampere Characteristic Curves for One-Photon (1) and Two-Photon (2) Emission From Lead Into Electrolyte

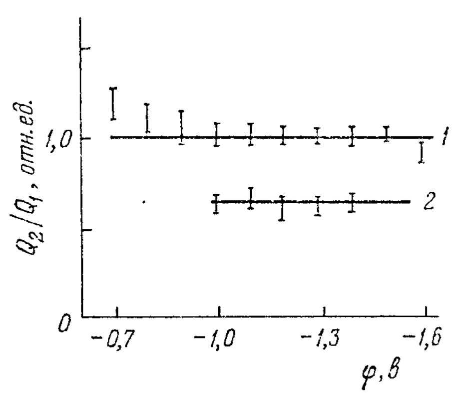


Figure 17. Independence of the Relationship Between Two-Photon and One-Photon Photoemission Signal From Electrode Potential. Curves: 1 -- lead; 2 -- mercury. Photoemission with n=1.2 is excited by radiation of a ruby laser and its second harmonic

Realization of the "5/2" law for two-photon photoemission occurs throughout the region of square-law variation Q (I).

Figures 16 and 17 show the relationship between emitted charge and potential for one- and two-photon photoemission from mercury and lead. Experimental data agree well with relations (4) and (5), whereby, in conformity with the theoretical prediction, the thresholds of one- and two-photon photoemission with photon energies $2\hbar\omega$ and $\hbar\omega$ coincide. Fulfillment of relation (5) for two-photon photoemission is confirmed in [46].

Change in the order of magnitude of photoeffect from n=2 to n=1 by changing the electrode potential was accomplished in the above-mentioned [43]. Figure 18, taken from this study, shows relation Q (ϕ), on which there are clearly evident two segments corresponding to one- and two-photon photoemission. In the two-photon photoemission region ($-0.5>\phi>-1.7$ V NKE), the emitted charge is proportional to the square of light intensity, while when $\phi<-1.7$ V this relation transitions to linear. The difference of potentials of extrapolation of the corresponding segments of relation Q (ϕ) is equal to 1.7-1.8 V and, in conformity with the theoretical prediction (relation (5)), within the limits of accuracy of measurement coincides with the energy of a laser quantum. The value of the quantum yield of the linear photocurrent, obtained from segment $\phi<-1.7$ V, comprises (1-2) x 10^{-4} electron/photon at a maximum emitted electron energy of E_m=0.5 ev, which agrees with measurement results at low light intensities. The j_2/j_1 ratio with equal E_m comprises (1-2) x 10^{-3} when I=1.5-2 Mw/cm^2. The η_2 value found from these data for two-photon photoemission from mercury into electrolyte (taken into consideration thereby is doubling of photoemission current by capture product reduction) comprises (1.5-0.7) x 10^{-14} a$\cdot$w^{-2}cm^{-2}.

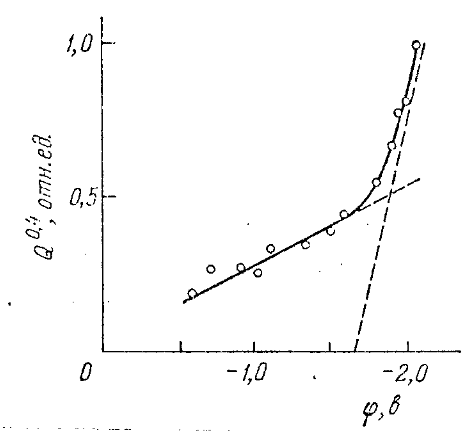


Figure 18. Change in Order of Magnitude of Photoeffect With Electrode Potential. 0.01 M $(C_2H_5)_4Cl$ solution, ruby laser, I=2 Mw/cm^2

This change in order of magnitude of photoemission from mercury also occurs under the effect of neodymium laser second harmonic pulses in the region of the potentials indicated in Table II.

For more accurate measurements of η_2, the values of charges emitted from one and the same metal target by the action of ruby laser first and second

harmonic pulses were compared [45]. The η_2 values contained in Table III, obtained by the same procedure, have been averaged from a large number of measurements for different specimens and can evidently be considered correct with an accuracy to a factor less than 2. The same table contains η_2 values obtained with measurements of two-photon photoemission into a vacuum.

Table III

Металл (1)	Условия фотоэмиссии (2)	Энергия кванта, эв (3)	Максимальная энергия электронов, эв (4)	η_2, $а \cdot вт^{-2} см^2$	Литература (5)
Натрий (6)	Вакуум (10)	1,48	0,7	$8 \cdot 10^{-16}$	34
		1,96	1,6	$9 \cdot 10^{-15}$	35
Золото (7)	»	3,57	2,3	$2,4 \cdot 10^{-15}$	15
Ртуть (8)	Электролит	1,78	1,2	$3,5 \cdot 10^{-14}$	45
Свинец (9)	» (11)	1,78	1,1	$7,3 \cdot 10^{-14}$	45

Key:

1. Metal
2. Conditions of photoemission
3. Quantum energy, ev
4. Maximum electron energy, ev
5. Bibliography
6. Sodium
7. Gold
8. Mercury
9. Lead
10. Vacuum
11. Electrolyte

As is evident from Table III, η_2 values for different metals lie in the range 10^{-15}–10^{-13} $a \cdot w^{-2} cm^{-2}$. Measurement results for silver and copper [43] give values $\eta_2 \sim 10^{-14}$ $a \cdot w^{-2} cm^{-2}$ (see Figure 13), which also fall within this range. In estimating spread of η_2 values within the limits of two orders of magnitude, one should bear in mind that measurements for sodium layers were performed in a vacuum of 10^{-6} torr, insufficient for obtaining a clean surface (see, for example, [48, 49]), while η_2 values for gold on the one hand and mercury and lead on the other pertain to photon energies which differ by double, while according to theory η_2 diminishes sharply with an increase in ω. The existence of such a relationship also follows from the results of preliminary measurements described in [44], where the authors compared the probabilities of two-photon photoemission from mercury under the effect of ruby laser and neodymium laser first harmonic pulses (the latter occurs when $\phi < -1.5$ V NKE) and it was found that in the latter case η_2 is approximately one order of magnitude larger than in the former.

The angular dependence of probability of two-photon photoemission from mercury ($\hbar\omega = 1.78$ ev), measured in [44], is shown in Figure 19. This same figure shows an analogous relation for one-photon photoemission obtained with the same photon energy for the same specimen. The latter is in good agreement with the angular relation of photocurrent measured in this study at low light intensities.

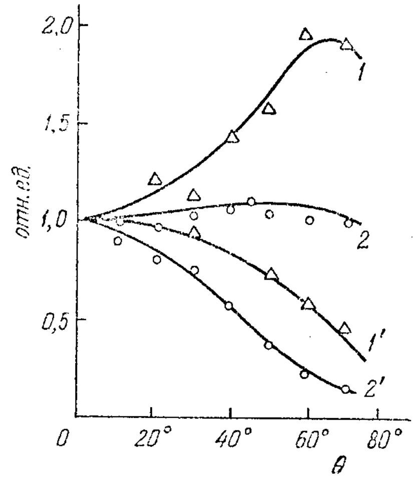


Figure 19. Relationship Between Emitted Charge Q (in Relative Units) and Angle of Incidence of Polarized Light. Curves 1,1' -- one-photon; 2,2' -- two-photon emission from mercury; 1,2 -- s-polarization; 1',2' -- p-polarization. Ruby laser, 2 Mw/cm^2

4. Experimental Investigation of Electron Emission From Metals Into a Vacuum Under the Effect of Picosecond Laser Pulses

We already noted in the introduction that nonlinear photoelectric effect at extremely high (in the order of 10-1,000 Gw/cm^2) intensities reveals a number of highly interesting features. Following the well-known Keldysh study [50], in recent years a number of theoretical studies have been published [23, 24, 51-54], in which the authors predicted deviation from the normal exponential relationship between density of emission current and laser intensity in the region of fairly high intensities. These studies aroused interest in experimental investigation of photoemission in strong optical fields.

Although intensities in the order of hundreds and thousands of Gw/cm^2 can be obtained in nanosecond pulses without particular difficulty, the latter prove unsuited for studying photoemission in this region of intensities. Indeed, as we already noted in Section 2, for nanosecond pulses the region of assured observation of multiple-photon emission is limited at the top to intensities in the order of 2-5 Mw/cm^2; at higher intensities thermionic emission caused by heating of the cathode begins to make a substantial contribution to the observed current. It was demonstrated in a study by Bunkin and Prokhorov [20] that much more favorable conditions for recording multiple-photon processes can be created by reducing the laser pulse duration and at the same time increasing radiation intensity. It was further shown in [8, 21] that when metal is heated by ultrashort pulses, the equilibrium between electrons and lattice will be disturbed, which should have a substantial effect on thermal emission in view of the small specific heat value of degenerate electron gas. A detailed calculation, to which

we shall return in Section 5, indicated that for pulses shorter than 10^{-11} sec, the region of observation of photoeffect on the background of thermal emission can be expanded to intensities in the order of 10-100 Gw/cm^2.

Equipment for generating ultrashort laser pulses was developed in 1966-1967. The first information on the parameters of these pulses was obtained with the aid of the two-photon fluorescence method. It was established that in self-synchronization mode a laser emits a train of 10-100 pulses of an average duration in the order of 10^{-12} sec, of an average power in the order of 1 Gw and interval between pulses of $\Delta t=2L/c$, where L is the length of the laser cavity and c is the speed of light. Subsequently investigators succeeded with electro-optical methods in separating an individual pulse from the train and performing a direct measurement of its duration, utilizing an image converter [55]. It was established as a result of such investigations that in the first half of the train, when there occurs an increase in intensity, each individual pulse possesses a Gaussian shape in time and spectrum with an average duration of approximately 6-7 psec. In the second part of the train, when intensity drops off, pulse duration increases to values in the order of 100 psec, while their time shape and spectrum become irregular and reveal a substructure.

Proceeding to discussion of investigations of nonlinear photoeffect under the influence of picosecond pulses, we shall note that by measuring photoemission of high orders of magnitude one can obtain useful information on the properties of the pulses proper, particularly on their temporal structure, spectral characteristics, coherence, etc.

a) Relationship Between Photocurrent and Radiation Intensity

First measurements of a lux-ampere characteristic curve in the picosecond range of pulse durations were performed in 1969 [56, 57]. The experimental setup described in [12, 38] was utilized with a laser operating in self-synchronization mode. A train of picosecond pulses was recorded by two photovoltaic detectors: a fast linear and a nonlinear, in which a metal cathode was employed. Signals from both detectors were fed to a high-speed oscilloscope. Thus in the experiment the authors measured linear and nonlinear current values, time-averaged for an interval determined by the oscilloscope band (in practical terms approximately 1 nsec), proportional to integrals

$$V_L \sim \int I\,dt, \qquad V_{NL} \sim \int I^n\,dt.$$

Obviously only when all pulses in the train possess identical time and spectral form can intensity I be replaced by quantity V_L, and photocurrent $j \sim I^n$ by quantity V_{NL}. Plotting on a double logarithmic scale V_{NL} as a function of V_L, we obtain a photoeffect lux-ampere characteristic curve.

In experiments [56, 57] investigators observed a nonlinear photoeffect of various orders of magnitude -- from second to fifth -- with laser intensity of approximately 1 Gw/cm^2. Precise absolute intensity values were not

measured in these experiments in view of then-existing difficulties with measuring duration of ultrashort pulses. Figure 20 contains a diagram of the experimental setup. The experiments employed ruby and neodymium glass lasers; gold and nickel as well as the semiconductor Cs_3Sb were employed as target material. We shall note that in the case of a neodymium laser and gold cathode, minor work function fluctuations can change the expected value of n from 5 to 4. Therefore for polycrystalline specimens one can observe both one and the other value of the order of magnitude of nonlinearity, depending on the structure of the specimen.

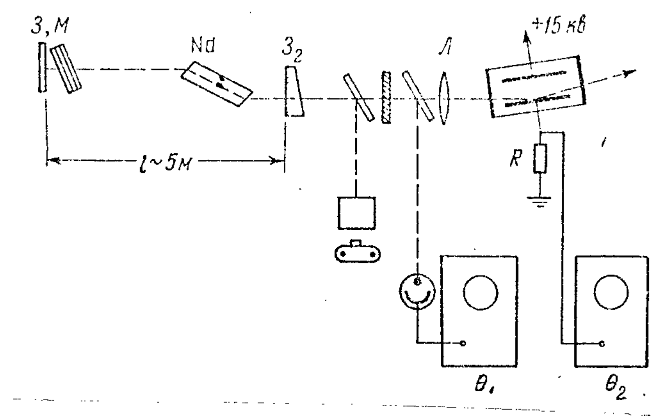


Figure 20. Setup for Examining Photoemission Under the Effect of Picosecond Pulses

As can be seen from Figure 21, pure multiple-photon photoeffect of the second, third, fourth and fifth order, without appreciable contribution by thermal emission, is observed in the described experiments. Experimental error in determining n was ±0.5*. We can note that there was observed in the experiment a certain current increase toward the end of the train, which was one of the first experimental indications of increase in the duration of individual pulses at the end of the train. In summing up we can state that the main value of experiments [56, 57] is that they confirmed the possibility of observing multiple-photon photoeffect in the intensity range ~1 Gw/cm^2 and higher. Thus there appeared the possibility of examining in detail the features of photoemission in strong fields.

The theory of photo- and thermal emission under the effect of picosecond pulses will be examined in detail in Section 5. Here, however, we should note two theoretical results which are important for understanding the experiments described below. The first pertains to the relationship between

* For the Cs_3Sb cathode, which was used as control, thermal effects began to appear at lower intensities than for metal cathodes, as a consequence of the poorer thermal conductivity of the Cs_3Sb.

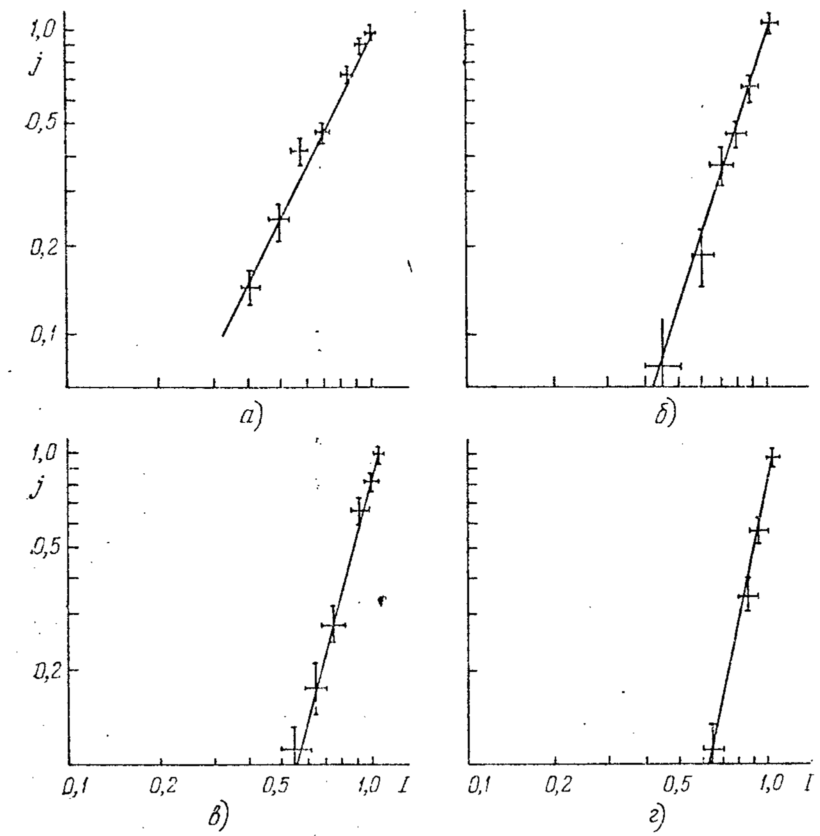


Figure 21. Lux-Ampere Characteristic Curves: a) cathode of Cs_3Sb neodymium laser, n=2; b) gold, ruby laser, n=3; c) gold, neodymium laser, n=4; d) Ni, neodymium laser, n=5.

photocurrent and intensity of radiation. At relatively low intensities, as we have seen above, photocurrent is an exponential function of radiation intensity. On the other hand, if the wave field intensity becomes so great that the probability of tunnel-type electron emission during one period is in the order of 1, the relationship between emission current and field intensity should develop into the well-known expression for field emission in a constant field. An analogous situation of course occurs for multiple-photon atom ionization [1]. A formula [50] which is valid both in weak and strong fields was first obtained precisely for this case. The critical field intensity value, according [15, 24, 50], is

$$\mathcal{E}_1^* \sim (\omega/e)\sqrt{2mA},$$

where e and m are charge and electron mass, and ω is the radiation frequency. For a neodymium laser and gold cathode our estimate gives a critical field value of

$$\mathcal{E}^* \sim 10^{7,3}\ \text{V/cm}.$$

This value was obtained without considering the Coulomb interaction between the emitted electron and the metal surface. Figuring in the latter reduces the critical field by more than one order of magnitude [23].

Secondly, as was demonstrated in [8, 21], the character of thermionic emission changes substantially in the picosecond pulse duration range. With such durations the electron subsystem proves to be isolated from the lattice and, in view of low heat capacity, is heated practically noninertially. As a result, for thermal emission under the effect of picosecond pulses, there is no current lag in respect to the laser pulse. It is difficult to observe such thermionic emission separately from photoemission in the most simple experiment; superposition of both mechanisms leads to a relationship between current and intensity differing from (1).

Experimental verification of these theoretical predictions was performed in [58]. The authors utilized an improved version of the experimental setup in [57]. Results were processed with the same method as in [57]. Radiation from a neodymium laser operating in self-synchronization mode was focused on the surface of the cathode. Measurements were conducted in the laser intensity range from 6.5 to 66 Gw/cm^2. Corresponding $\mathcal{E}_\perp$ values ranged from $10^{6,3}$ to $10^{6,8}$ V/cm. Figure 22 shows the results of the experiment. One can see that with field normal component values $\mathcal{E}_\perp \sim 10^{6,8}$ V/cm, one observes a deviation from the normal exponential function of emission current.

However, the experimentally measured critical field intensity value corresponding to the beginning of deviation is somewhat less than the value $10^{7,3}$ V/cm predicted theoretically [24]. We should note, however, that accuracy of absolute field intensity measures was not very high, since the utilized two-photon fluorescence method gave pulse duration values averaged for the train. At the same time experiments showed that the magnitude of the emission currents and the statistical spread of data are strongly dependent on the parameters of the ultrashort pulses and their distribution within the train.

A more detailed study of these same questions was undertaken in [59]. The setup described in [58] was employed. Signals from the linear detector and photocathode were passed through a delay line and fed together to a high-speed oscilloscope. The signals constituted trains of current pulses (Figure 23). Duration of the signal from the nonlinear photocathode, measured by the envelope, proved to be less than the duration of the linear signal. Figure 24 contains a lux-ampere characteristic curve calculated from the data in Figure 23. This curve consists of three different parts. A straight line with an angle of slope of 5, describing photoemission with absorption of five quanta, corresponds to the initial segment of the train, on which intensity increase occurs. With an increase of maximum intensity the slope angle decreases in conformity with theoretical predictions [24,23, 50, 54] and the result obtained in [58]. Finally, the third part of the curve, corresponding to the segment of the train with diminishing intensity, displays an unexpectedly sharp increase in slope angle. In connection with the fact

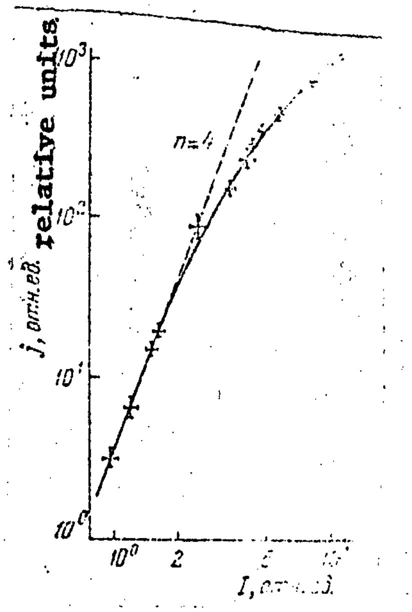


Figure 22. Decrease in Degree of Nonlinearity at High Intensities

that such a strong relationship between current and intensity is difficult to explain proceeding from existing theoretical concepts, the authors of [59] undertook a more detailed investigation of the question.

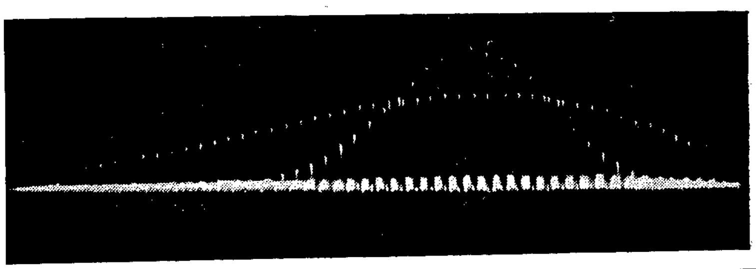


Figure 23. Oscillograms of Linear and Nonlinear Signals

It turned out that the observed peculiarities are partially connected with the structure of the pulse trains, which had been studied in [55]. In those cases where Q modulation took place with the aid of a clarifying filter with small initial absorption, the generated pulses revealed a regular structure which was disturbed only toward the end of the pulse. With a high initial dye absorption, at the beginning of the train pulses had a duration of approximately 50 psec, a substructure with a period in the order ot 10^{-13} sec, and an irregular spectral distribution. In [59] the authors concluded that for ultrashort laser pulses with reproducible structure, the theoretical predictions in [23, 24] are qualitatively confirmed both in the region of moderate and in that of high intensities. As for longer pulses with irregular and poorly reproducible structure, the increase in order of magnitude of nonlinearity observed for them may involve

the new type of thermionic emission discussed in [21, 22]. Experiments [60, 61] were performed for a detailed examination of this question, with utilization of monopulses of several tens of picoseconds in duration. A single picosecond pulse was isolated from the train with the aid of a (Pokkel's) cell and was passed through three amplifier stages. The yttrium-aluminum garnet and neodymium driving oscillator operated in self-synchronization mode with one transverse mode. The pulse shape was recorded by an image converter and was Gaussian with a halfwidth of 30 psec. The remaining components of the experimental setup were identical with those employed in [59]. The experiments were performed with a gold cathode. The beam struck the cathode surface tangentially, with vector $\vec{\mathcal{E}}$ directed perpendicular to the surface.

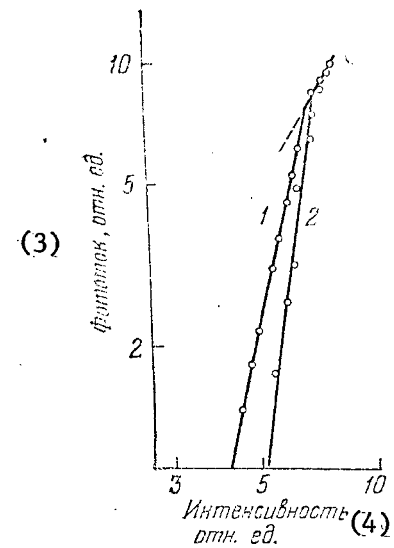


Figure 24. Relationship Between Photocurrent and Intensity. The laser beams a train of picosecond pulses. 1 -- segment of train with increasing intensity, 2 -- segment with diminishing intensity, 3 -- photocurrent, relative units, 4 -- intensity, relative units

Figure 25 shows on a log-log scale emission current as a function of radiation intensity (relative units). Each point on the graph is the average of 20 measurements. Right up to intensity in the order of several Gw/cm^2, the lux-ampere characteristic curve remains a straight line with a slope angle of 5, that is, pure five-quantum photoeffect is taking place. Deviations from this relation begin with a field intensity of $\mathcal{E}^* \sim 10^{6,3}$ V/cm, which is in agreement with previously-obtained results [58, 59]. We shall note that a theoretical calculation [24] gives a much larger value for critical field intensity: $\mathcal{E}^* \sim 10^{7,3}$ V/cm. In [24, 54, 62] the authors point out that in calculating critical field one should take into account Coulomb interaction of emitted electron with metal. However, the estimate in [23, 54], taking

this effect into account, gives for the critical field an excessively low value $\mathcal{E}^* \sim 10^5$ V/cm, which is also not in agreement with the experiment. We shall return to this question in Section 5 when discussing theory of nonlinear photoeffect.

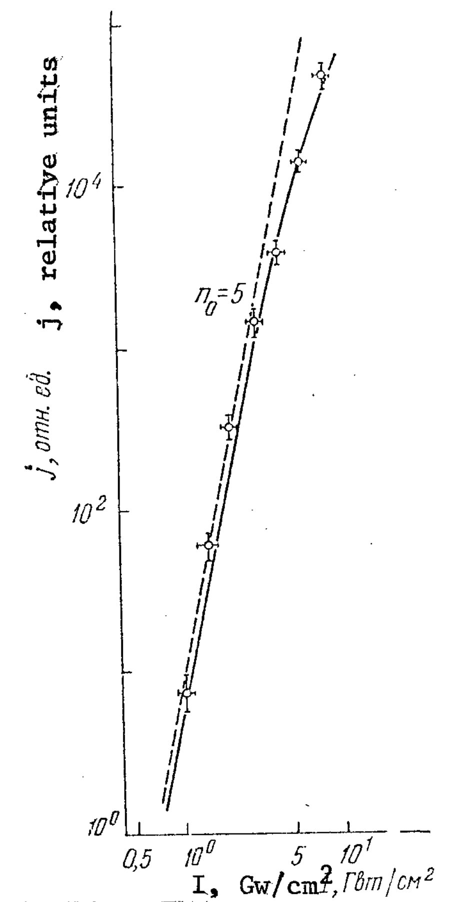


Figure 25. Decrease in the Order of Magnitude of Photoeffect with Increase in Intensity

We shall note that the possible cause of discrepancies between theory and experiment in principle may be inaccuracy in experimental determination of field intensity. It is little probable, however, that the latter can lead to a 10-fold decrease in field intensity.*

Measurements on a tungsten cathode, similar to those described, with employment of the same experimental equipment as in [60, 61] were performed

* The $\mathcal{E}^*$ values given were computed from average radiation intensity values by time and focusing spot.

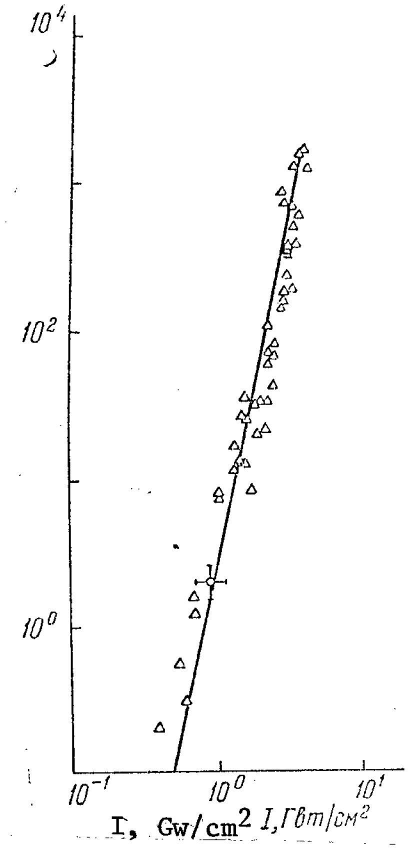


Figure 26. Photoemission (j, a/cm^2) From Tungsten Surface Under the Effect of Picosecond Pulses

in [62]. For values $\mathcal{E}_\perp$ not exceeding $10^{6,2}$ V/cm (intensity was computed on the basis of intensity at laser pulse maximum), the authors of this experiment observed multiple-photon photoemission with n=4 (Figure 26). Thus it follows from [60-62] that under the effect of smooth individual picosecond pulses one observes photoemission with a degree of nonlinearity of

$$n = n_0 = \langle 1 + (A/\hbar\omega)\rangle ,$$

and one does not observe n values exceeding n_0. Previously it was demonstrated in [59] that emission with $n>n_0$ is observed on the diminishing segment of the train of picosecond pulses approximately in the same intensity interval. In order to be convinced that the occurrence of abnormal emission with $n>n_0$ is connected not with the properties of the train but with the structure of individual pulses, in [63] the authors examined emission under the effect of individual picosecond pulses of two types: a) smooth Gaussian pulses of ~6 psec duration, isolated from the train segment with increasing intensity; b) pulses with a marked substructure of ~50 psec duration, obtained when utilizing a clarifying filter with high intial absorption. It

was demonstrated that pulses of type a excite photoemission with $n=n_0=5$ (cathode of gold, neodymium laser). Figure 27 contains a lux-ampere characteristic curve for this case.

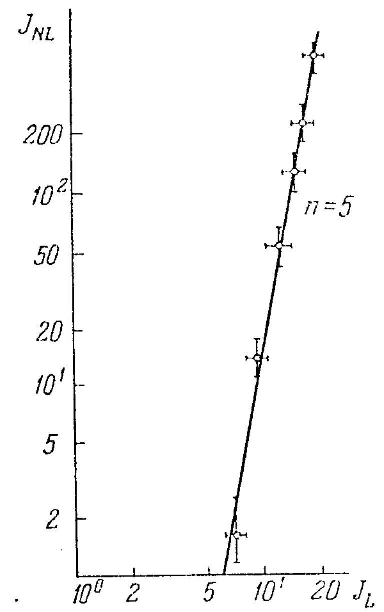


Figure 27. Photoemission Under the Influence of a Single Picosecond Pulse Without Substructure (gold, neodymium laser)

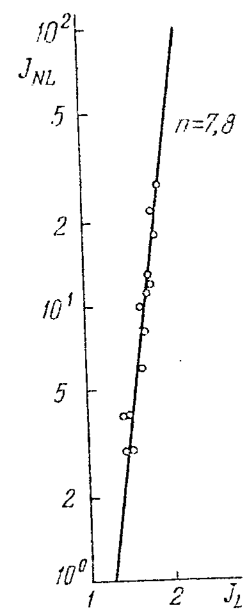


Figure 28. Photoemission Under the Influence of a Single Picosecond Pulse With Marked Substructure (gold, neodymium laser)

As is evident from Figure 28, values of $n>n_0$ were obtained with pulses of type b. Emission current also reveals a sharp polarization relationship. Precise measurement of intensity for type b pulses proved impossible; however, an estimate on the basis of measured parameters gives values in the order of several Gw/cm^2.

The occurrence of emission with $n>n_0$ together with a sharp polarization relation for type b pulses indicates that the observed current is a superposition of photocurrents of different orders of magnitude, excited simultaneously. This type of emission was predicted in [64], where it was shown that for total current values $n=d \ln j/d \ln I$ may exceed n_0.

b) Relationship Between Emission Current and Polarization of Radiation

Since surface and interior photoelectric effect and thermionic emission can possess close lux-ampere characteristic curves within a narrow range of intensities, knowledge of the latter is insufficient to elucidate the emission mechanism. In connection with this measurements were made [60] of the polarization relation of emission current. The measurement method was in its general features similar to the one described above (see Section 2).

The direction of polarization of light striking the cathode was changed by rotating the Glan-Thompson prism placed on the path of the laser beam. Measurements were conducted in a range of intensities where the relation $j \sim I^n$ is realized. Change of parallel $\mathcal{E}_\parallel$ and perpendicular $\mathcal{E}_\perp$ of the electrical field components depends on how the initial (in the absence of a prism) laser beam polarization is oriented in respect to the cathode surface. We shall examine two instances.

In the first instance, shown in Figure 29, the direction of polarization of the incident beam is determined by angle ϕ between the plane of oscillations of the electrical vector and the normal to the cathode surface. For field components we have

$$\mathcal{E}_\perp(\varphi) = \mathcal{E}_0 \cos^2 \varphi,$$
$$\mathcal{E}_\parallel(\varphi) = \mathcal{E}_0 \cos \varphi \sin \varphi.$$

From the figure one can see that the photocurrent being measured depends only on field component $\mathcal{E}_\perp$ and is described by the formula

$$j = |\mathcal{E}_\perp(\varphi)|^{2n} = \mathcal{E}_0^{10} \cos^{20} \varphi,$$

which corresponds to surface photoeffect of the fifth order. The influences of the parallel surface of the field component cannot be observed even with a maximum value of the latter $\mathcal{E}_\parallel = \mathcal{E}_0/2$.

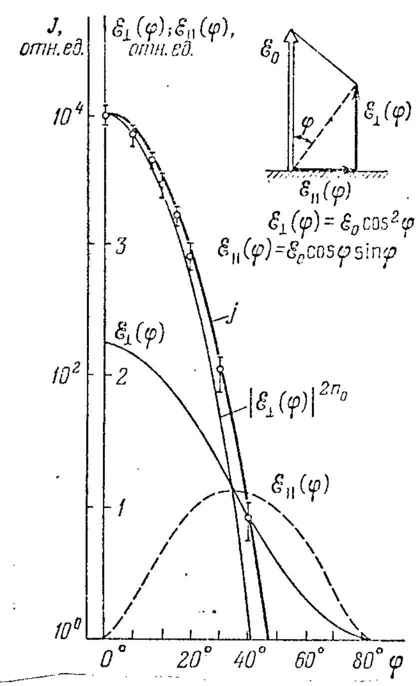


Figure 29. Polarization Relationship of Photocurrent. Diagram of Experiment Shown at Upper Right

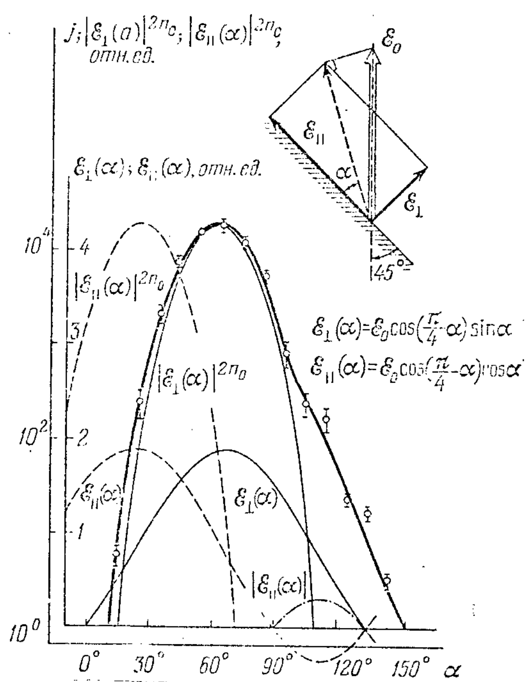


Figure 30. Polarization Relationship of Photocurrent With Altered Experiment Geometry. Diagram of Experiment Shown at Upper Right

In the second case, shown in Figure 30, the field components are determined by angle α between the plane of oscillations of the wave electrical field and the cathode surface. If the cathode surface comprises an angle of 45° with the initial direction of electrical vector polarization, the relationship between field components and α is given with the formulas

$$\mathscr{E}_{\perp}(\alpha) = \mathscr{E}_0 \cos\left(\frac{\pi}{5} - \alpha\right) \sin\alpha,$$

$$\mathscr{E}_{\parallel}(\alpha) = \mathscr{E}_0 \cos\left(\frac{\pi}{4} - \alpha\right) \cos\alpha.$$

Maximum values of the components are equal to $\mathscr{E}_{\perp\,\max} = \mathscr{E}_{\parallel\,\max} = \mathscr{E}_0/\sqrt{2}.$

The experimentally measured relationship between emission current and angle α coincides with the expected relation

$$j \sim |\mathscr{E}_{\perp}(\alpha)|^{2n} = \mathscr{E}_0^{10}\left[\cos\left(\frac{\pi}{4} - \alpha\right)\sin\alpha\right]^{10}$$

through almost the entire range of change of α. A slight deviation revealed at angles $\alpha \gtrsim 90°$ is of interest. It is significant that current is determined only by the normal field component even in the region of maximum $\mathcal{E}_{\parallel}$, while deviations from this relation begin at $\alpha \approx 90°$, when component $\mathcal{E}_{\parallel}$ changes sign. This unexpected fact requires additional investigation.

It is interesting to note that a pronounced polarization relationship is observed not only for smooth pulses but also for isolated pulses with a substructure to which a lux-ampere characteristic curve with a slope of $n > n_0$ corresponds [63].

Summarizing the cited results, we can conclude that in the investigated case (cathode of gold, neodymium laser) emission of electrons is entirely caused by surface photoeffect. Change in the lux-ampere characteristic curve with increase in field intensity is qualitatively in conformity with theoretical predictions. An abnormal change in the lux-ampere characteristic curve and observation of a relation with $n > n_0$ observed in a number of experiments is connected with an irregular structure of laser pulses.

5. Theory of Nonlinear Photoelectric Effect

The single-photon instance has been most fully investigated in theory of photoeffect. Comparatively few studies have been devoted to multiple-photon photoemission, and almost all apply to surface photoeffect.

In a general statement of the problem, theoretical studies of photoeffect naturally divide into two groups. The first includes calculations of photoemission based on phenomenological models of the process of interaction between light and electrons in a metal. The simplest of these model theories, developed in [65], constituted one of the first applications of quantum mechanics in solid state physics. The approach suggested in [65]

proved highly fruitful, and for a long time development of photoeffect the theory proceeded in the direction of improving phenomenological models. Investigators sequentially studied the influence on emission current of the shape of the potential barrier on the metal-vacuum boundary, temperature, nonidealness of surface, and periodic lattice field. We should note that in spite of the obvious inconsistency of the phenomenological approach, which has been noted time and again by its critics, and the excessive simplification of the examined models, as a rule the results of computations proved to agree very well with the experiments. The phenomenological approach in theory of photoeffect has retained its significance up to the present time. Suffice it to note that a substantial portion of results in theory of interior and nonlinear surface photoeffect were obtained through examination of models and are in reasonable agreement with experiments.

The second group comprises studies in which a sequential quantum-mechanics statement of the problem of photoemission is developed. The most important result of these studies was an understanding of the reasons for the success of and limits of applicability of phenomenological theories of photoelectric effect. A very convenient approach to calculating photoemission, based on threshold approximation in the problem of scattering, was suggested in [23]. A different, equivalent in general features, formalism was employed in [66, 67]. It is significant that the approach developed in [23, 66, 67] makes it possible to take into consideration in a natural fashion multiple-electron effects [35, 68]. The principal computation method in studies of the second group is perturbation theory, which is very convenient in calculations of one-photon emission. Of fundamental interest in the multiple-photon instance are strong optical fields in which the condition of applicability of perturbation theory may be violated. A number of results for this instance were obtained in [23] by taking into account within the framework of the scattering problem interaction in a final state.

In this subsection we shall describe the principal methods of calculating photoemission and the results obtained with their assistance, focusing particular attention on the case of strong optical fields and certain effects characteristic of the laser method of exciting photoemission.

a) Nonstationary Perturbation Theory. A Phenomenological Approach

We shall begin with model calculations of photoemission current in fields which are weak in comparison with intraatomic fields. Calculations of this kind for one-photon photoeffect have been performed by many authors (see [19]); two-photon emission was examined in [13, 69], and three-photon in [33]. The model character of calculation consists in the fact that in place of interaction between light and metal one is examining absorption of light by an electron located in some one-dimensional potential field. The most frequently studied is the Sommerfeld model, in which potential has the form of a step: $V(x)=V_0\theta(x)$. The external field is assumed weak and is viewed as perturbation.

Electron motion in the field of a light wave and potential is described by the Schroedinger equation

$$i\hbar \frac{\partial \psi}{\partial t} = \mathcal{H}\psi \qquad (6)$$

with Hamiltonian

$$\mathcal{H} = -\frac{\hbar^2}{2m}\Delta + V(x) + \frac{ie\hbar}{mc}\mathrm{A}\nabla + \frac{e^2}{2mc^2}\mathrm{A}^2,$$

where A(r, t) is the light wave vector-potential; the remaining designations are conventional. From the solution of equation (6) we calculate in a normal manner current as a function of electron pulse

$$\mathbf{j}(\mathrm{p}) = \frac{ie\hbar}{2m}(\psi\nabla\psi^* - \psi^*\nabla\psi) - \frac{e^2}{mc}\mathrm{A}\psi^*\psi.$$

The observed current density is obtained from this by averaging by Fermi distribution W(p):

$$\mathbf{j} = \int d\mathrm{p}\, W(\mathrm{p})\, \mathbf{j}(\mathrm{p}). \qquad (7)$$

In a weak field the solution of Schroedinger equation (6) can be sought in the form of a series by degrees of vector potential. Assuming in (6) $V(x)=V_0\theta(x)$, A= a cos ωt, we shall write down the wave function in the form

$$\psi = \sum_{k=0}^{\infty} \psi_k \exp\left[-i\left(k\omega + \frac{E}{\hbar}\right)\right], \qquad (8)$$

where $E=p^2/2m$ is electron energy in the absence of a field and

$$\psi_k \sim |a|^k \sim |\mathcal{E}_0 c/\omega|^k.$$

In our further discussion we shall follow [70], in which the perturbation theory calculation was performed for photoemission of any order. Following as particular cases from the results of this study are the formulas in [13, 19, 33, 69]. We shall assume that an electromagnetic field penetrates into the metal. Such an assumption is evidently more natural when studying surface photoeffect than the assumption of a field discontinuity on the surface. We shall note that field and electron effective mass discontinuities on the surface can make an additional contribution to photoexcitation, and their inclusion should lead, speaking in general terms, to a certain increase in emission current. When necessary these effects can be included in an obvious manner in the calculation presented below.

Substituting (8) in (6) and shifting for convenience to atomic units, we obtain a chain of equations for functions ψ_k of the type

$$\left(-\frac{1}{2}\Delta + V(x) - E - k\omega\right)\psi_k + \frac{i\mathcal{E}_0}{2\omega}\nabla\psi_{k-1} + \frac{\mathcal{E}_0^2}{8\omega^2}\psi_{k-2} = 0. \qquad (9)$$

Since the coefficients in the equations are piecewise-constant, the solution of equation (9) is written down in the form of a combination of exponential functions, coefficients with which are determined from the conditions of matching of ψ_k and their derivatives with x=0. Omitting the details of the computations, we shall present the final expression for current density (dimensional variables):

$$\left.\begin{aligned} j_n &= \int\limits_{M_n}^{\infty} dp_x f_n(p_x) \ln\left\{1+\exp\left[\frac{E_F-(p_x^2/2m)}{kT}\right]\right\}, \\ f_n(p_x) &= \frac{\sqrt{2}}{\pi^2}\frac{ekT}{mch^3} p_x^2 \sqrt{p_x^2+2m(nh\omega-V_0)} \times \\ &\quad \times \left|D_n\left[i\sqrt{n+\frac{p_x^2}{2mh\omega}}\right]\right|^2 \left(\frac{e^2\mathcal{E}_\perp^2}{2mh\omega^3}\right)^n, \\ M_n &= \begin{cases} 0, & V_0 < n\hbar\omega, \\ \sqrt{2m(V_0-n\hbar\omega)}, & V_0 > n\hbar\omega, \end{cases} \end{aligned}\right\} \qquad (10)$$

where $D_n(x)$ is a certain function for which a recurrence formula is given in [70]. When n=0 formula (10) gives thermionic emission current. When n=1, 2, 3, known results [13, 19, 33, 69] follow from it.

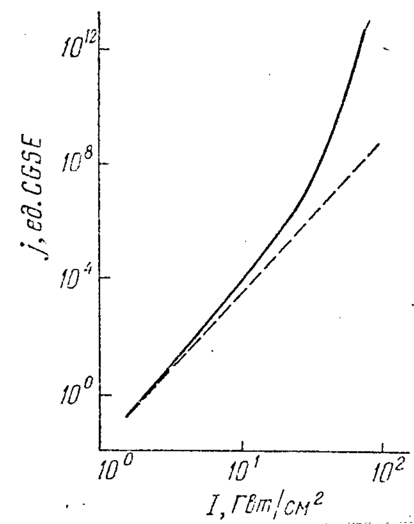


Figure 31. Photoemission From Silver. Calculation according to perturbation theory. The solid line takes into account cathode heating, and the dashed line assumes zero cathode temperature

Calculating the quadrature in formula (10) with a known relationship between cathode temperature and laser intensity, one can determine the lux-ampere characteristic curve of nonlinear photoeffect. In many studies effects connected with heating were not taken into account, and integrals of type (10)

were calculated with T=0. If such a calculation is performed in our case, we obtain an exponential function of photocurrent and the normal wave electrical field component to the cathode surface. As an example, the dashed line in Figure 31 shows a lux-ampere characteristic curve for silver and a neodymium glass laser, calculated without considering photocathode heating. It corresponds to the relation $j \sim I^5$. The solid-line curve in the same figure shows the actual lux-ampere characteristic curve taking into account photocathode heating (for calculation of the latter, see below). In addition to the obvious difference between curves at high intensities, we should note that emission current, portrayed by a solid curved line, is determined not only by the normal electrical field component to the metal surface but also by the tangential components as well. The aggregate current, formed of partial currents with differing degrees of nonlinearity, reveals a complex polarization relationship.

It is evident from (10) that the expansion in (8) proceeds by powers of parameter

$$\Delta/\hbar\omega \approx e^2 \mathcal{E}_{\perp}^2/m\hbar\omega^3 .$$

Therefore for applicability of perturbation theory it is necessary for the energy of classic electron oscillations in a light wave field to be small in comparison with the work function. Naturally for estimating the area of applicability of a solution obtained with the aid of perturbation theory and the character of deviations from this solution an approach is required which does not utilize the assumption of wave field weakness. Such an approach was first proposed by Keldysh [50] and applied to the problem of photoemission in [15, 24]. We shall discuss some of the results of these studies.

b) Photoemission at High Intensities. Limits of Applicability of Perturbation Theory

The authors of [15,24, 50] study electron transfer to a final state corresponding to its motion in a strong light wave field. In this manner the effect of the influence of a strong ffield on a free electron is precisely taken into account. It is demonstrated in [62] that it is simpler to obtain basic results [50] by a quasi-classical method. Here we shall follow, however, the method employed in [50], which makes it possible for the simplest metal model to obtain essentially a precise solution to the problem of nonlinear photoemission [24]. Certain computational difficulties of course arise thereby, requiring application of numerical methods for obtaining a lux-ampere characteristic curve [22].

In [24] the author examines a Sommerfeld metal model, in which electrons comprise particles with a certain effective mass, which are subordinated to Fermi statistics and which move in a constant potential field. At the metal boundary the potential experiences jump V_0. Electron motion is described by Schroedinger's nonstationary equation (an atomic system of units is employed)

$$i\frac{\partial\psi}{\partial t} = \mathcal{H}\psi.$$

Hamiltonian $\mathscr{H} = \mathscr{H}_0 + \mathscr{H}_{\rm int}$, where $\mathscr{H}_0 = -(1/2)\,\Delta - V_0\theta\,(-x)$,

$$\mathscr{H}_{\rm int} = \theta\,(x)\left(-\frac{i\sin\omega t}{\omega}\,\mathscr{E}_0\nabla + \frac{\mathscr{E}_0^2}{2\omega^2}\sin^2\omega t\right). \qquad (11)$$

Cited notation $\mathscr{H}_{\rm int}$ corresponds to a model in which the field does not penetrate into the metal (precisely this case was examined in [24]). The solution can be generalized to the case of any field discontinuity on the metal surface. For this it is necessary to add to $\mathscr{H}_{\rm int}$ a term analogous to (11), with $\tilde{\mathscr{E}}_0$ in place of $\mathscr{E}_0$ and $\theta(-x)$ in place of $\theta(x)$, and to introduce the corresponding factors in expressions for wave functions.

In [24] the author writes out solutions to the Schroedinger equation in regions x<0 and x>0 and joins the solutions at the metal-vacuum boundary. The condition of joining comprises an infinite system of transcendental equations the solution of which in general form presents considerable difficulty. Analysis indicates, however, that if field intensity satisfies condition

$$\left|\frac{\mathscr{E}_0^2}{4\omega^4}\right| \ll 1, \qquad \left|\frac{\mathscr{E}_0^4}{256\omega^6}\right| \ll 1, \qquad (12)$$

the system of equations can be simplified and its approximate solution found. Details of fairly cumbersome calculations are described in [24]. We shall note that even after simplications, calculation of an integral of type (7) presents some difficulty and is performed [24] with the theorem of the mean. A final result for cathode zero temperature is given by the formula

$$j_m(\mathscr{E}_0,\omega) = (m!)^2\left(\frac{\mathscr{E}_0^2}{2\omega^3}\right)^m \frac{2E_F^{5/2}}{30\pi^2\,(m\omega)^m\,(2\omega)^{1/2}}\times$$
$$\times\left[1-\frac{1}{2}\,\theta\,(\tilde{V}-m\omega)\left(\frac{\tilde{V}-m\omega}{E_F}\right)\left(5-3\,\frac{\tilde{V}-m\omega}{E_F}\right)\right]\overline{C}, \qquad (13)$$

where $\tilde{V} = V_0 + \frac{\mathscr{E}_0^2}{4\omega^2}$, $\quad m = \left\langle \frac{A + (\mathscr{E}_0^2/4\omega^2)}{\omega} + 1\right\rangle$, $\quad \overline{C} \approx 1$.

Formula (13) in its general features suggests the formulas obtained within the framework of perturbation theory. A substantial difference, however, lies in the fact that (13) contains potential well depth $\tilde{V}$, measured not from vacuum level but from average electron oscillation energy in wave field $\mathscr{E}_0^2/4\omega^2$. There is an exponential function relationship between emission current and light intensity. The exponent itself, however, proves to be a slowly varying function of intensity. Conditions (12), utilized in deriving formula (13), are fulfilled if the following inequality is realized:

$$\gamma = \frac{\omega}{\mathscr{E}_0}\sqrt{2V_0} \gg \frac{V_0}{\omega} \approx n.$$

Parameter γ on the left side of the inequality has a simple meaning [15, 50]: it is equal to the ratio of light frequency to frequency of tunneling, that is, inverse time of electron passage through the potential barrier. Values $\gamma \ll 1$ correspond to a region of frequencies and field intensities in which tunneling occurs in a time much less than the period of the field. Current within this limit is described by known formulas for emission in a constant electrical field [71]. According to [15, 50], the opposite extreme case $\gamma \gg 1$ should correspond to perturbation theory. Analysis [24] indicates, however, that for photoemission of high orders of n, the condition of applicability of perturbation theory proves to be more rigid: $\gamma \gg n$. It is demonstrated in [24] that in intermediate region $1<\gamma<n$ the angle of slope of the lux-ampere characteristic curve d ln j/d ln I becomes less than in the region of low intensities, where perturbation theory is applicable. This result is in qualitative agreement with experimental results; however, measured field intensity at which deviations from perturbation theory begin differ from the theoretical estimate by approximately one order of magnitude. The probable reason for the discrepancy is failure to take into account [24] Coulomb interaction between emitted electron and metal surface. Coulomb corrections with a different method of solution were evaluated in [23]. In an analogous problem on multi-photon ionization of atoms, this effect was examined in [72, 73] (see review of the question in [62]). The methods employed in these studies do not provide the possibility of obtaining rigorous quantitative results in a region of field intensities which is of practical interest. It is understandable, however, that in figuring in Coulomb interaction there is an increase in the size of the spatial region in which the potential gradient differs from zero, and the probability of photoionization increases. There occurs thereby a decrease in critical field intensity corresponding to change in the degree of process nonlinearity. These conclusions are in qualitative agreement with experiments both on multiple-photon ionization of atoms and on nonlinear photoeffect from the surface of metals under the effect of laser radiation. However, a quantitative solution to this problem has not yet been obtained.

c) Influence of Cathode Heating On Photocurrent Characteristics

Temperature effects are figured automatically if averaging according to formula (7) is performed taking into account the cathode temperature, which is determined by conditions of irradiation. In order to determine the latter is is necessary to solve the problem of thermal conductivity for metal heated by a laser pulse. This question was examined in detail in [8, 30]. We shall discuss here the most interesting instance of effect of a picosecond laser pulse on metal.

Absorption of light in metal leads directly to an increase in electron energy; heating of the lattice takes place as a result of a relatively slow relaxation process, the dynamics of which are conveniently described in terms of Cherenkov phonon radiation by nonequilibrium electrons [74].

Characteristic lattice heating time due to exchange of energy with electrons is equal by order of magnitude to 10^{-10} sec. For shorter laser pulses lattice heating during the pulse is negligibly small. In view of the fact that at temperatures much less than Fermi energy, heat capacity of the electron subsystem is small, it is easy to comprehend that in a very short time the energy-absorbing electrons heat to a certain quasi-stationary temperature determined by the balance between the power obtained from the light wave and the power expended on Cherenkov phonon radiation and heat flow deep into the metal. Thus for electron subsystem temperature there occurs the equation

$$\frac{\partial}{\partial x}\left(\chi_e \frac{\partial T_e}{\partial x}\right) - \alpha T_e - (1-R)\frac{\partial I(x, t)}{\partial x} = 0 \qquad (14)$$

where α is the "coefficient of heat exchange" between electrons and lattice, equal, according to [74], to approximately 10^{17} e/cm^3 sec·degr. It follows from (14) that surface temperature is equal to

$$T_e(0, t) \approx \frac{(1-R)\, I(0, t)}{\sqrt{\alpha\chi_e}}. \qquad (15)$$

It is significant that as a consequence of the low heat capacity of electrons, their temperature can "follow" the intensity of laser radiation, and therefore thermionic emission shows practically no lag behind the laser pulse. In actuality electron thermal capacity is finite, and a small lag, comprising by order of magnitude

$$c_e/\alpha \sim (c_i/\alpha)\, kT_e/E_F \sim 10^{-12}\ сек,$$

occurs. A more precise calculation of electron temperature and thermionic emission has been performed in [21]. It follows from this calculation that for laser pulses ranging from several picoseconds to several tens of picoseconds in duration, electron temperature with a good degree of accuracy is a function of instantaneous laser radiation intensity, so that it makes sense to speak of a normal lux-ampere characteristic curve with the presence of appreciable photocathode heating (in the general case, with the existence of temperature lag relative to the laser pulse, one could speak only of a relationship between full emitted charge and laser pulse parameters).

We shall examine how cathode heating affects the lux-ampere characteristic curve. Let the minimum number of photons required for electron emission equal n_0 at cathode zero temperature. Cathode heating leads to the appearance of electrons with energy higher than Fermi level, and therefore the process of emission with absorption of a smaller number of photons than n_0 becomes possible. It is easy to see that by order of magnitude the ratio of n-photon and n-1-photon currents is equal to

$$\frac{j_n}{j_{n-1}} = c_n \frac{\Delta}{\hbar\omega} \exp\left(\frac{\hbar\omega}{kT}\right) = c_n \xi(I),$$

where

$$\xi(I) = \frac{I}{I_2} \exp\left(\frac{I_1}{I_0 + I}\right),$$

$$I_0 = \frac{T_0 \sqrt{\alpha \chi_e}}{1-R} \sim \frac{10^5 T_0}{1-R}, \quad I_1 = \frac{\hbar \omega I_0}{kT_0} \sim \frac{10^{-6} \omega}{1-R}, \quad I_2 = \frac{mc\hbar\omega^3}{2\pi e^2} \sim 2 \cdot 10^{-31} \omega^3$$

and initial cathode temperature is designated through T_0. Relation (15) was employed in deriving the written formulas. Full current is equal to

$$j = j_{n_0} P(\xi),$$

where $P(\xi)$ is a certain polynomial of degree n_0. Calculating the exponent of nonlinear total current

$$n = \frac{d \ln j}{d \ln I} = n_0 + \delta(I),$$

it is easy to see that at low intensities $I < I_0^2/I_1$ complement $\delta(I)$, deriving from temperature effects is negative, which is in conformity with the results of experiments [11]. When $I \sim I_0^2/I_\omega$ complement $\delta(I)$ changes sign and remains positive right up to intensities in the order of I_1. Thus the observed angle of slope of the lux-ampere characteristic curve should be determined by intensity in a fairly complex fashion.

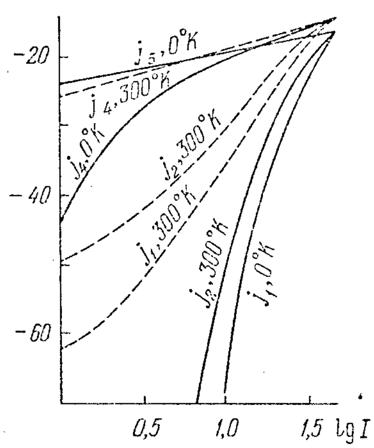


Figure 32. Relationship Between Emission Current, Components and Intensity (Gold, Neodymium Laser)

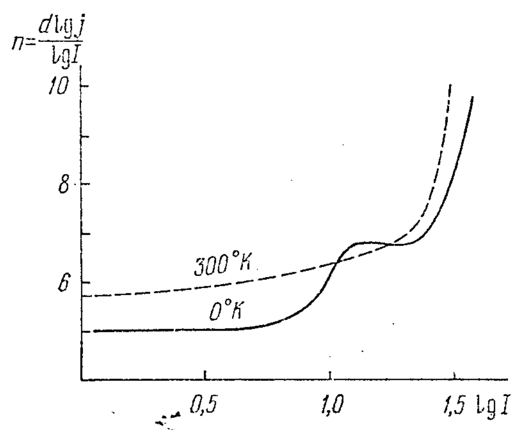


Figure 33. Relationship Between Order of Magnitude of Nonlinearity and Intensity of Radiation (Gold, Neodymium Laser)

The cited estimates indicate the necessity of rigorously taking into account temperature effects in multiple-photon emission. Corresponding calculations were performed in [22]. Partial currents as electron quasi-momentum functions corresponding to absorption n_0, n_0-1, etc photons were calculated by numerical methods with utilization of the Silin model [24]. Then averaging was performed, employing Fermi distribution with temperature,

determined by laser intensity [21]. Calculation results are contained in figures 32 and 33 for gold and neodymium laser radiation (n_0=5). Figure 32 shows the relationship between radiation intensity and averaged partial currents with n from 1 to 5. The curves were calculated for two values of initial temperature and coefficient of cathode reflection R=0.99. Figure 33 shows the relationship between the order of magnitude of nonlinearity of total current and laser intensity. It follows from the calculations in [22] that in the examined range of intensities $\delta(I)$ is positive. With intensity in the order of 15 Gw/cm^2, one adds to the basic five-quantum current four-quantum current, the contribution of which increases rapidly with an increase in intensity. When I~40 Gw/cm^2, contributions from all transfers with $n \leq 4$ become of one order. The contribution of current j_6 remains negligibly small.

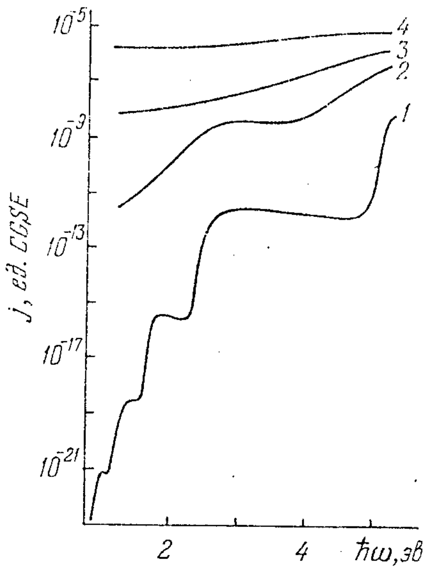


Figure 34. Relationship Between Photocurrent and Photon Energy at Various Light Intensities. 1 -- 10^9, 2 -- 4 x 10^{10}, 3 -- 7 x 10^{10}, 4 -- 10^{11} w/cm^2. Cathode of silver; calculation by perturbation theory

A calculation of a lux-ampere characteristic curve for silver and neodymium laser radiation analogous to that described above was performed in [70]. Current densities in relation to electron quasi-momentum were calculated by the perturbation theory developed in [70]. Then averaging was performed, by energy distribution of electrons with the temperature calculated in [21]. The result is indicated by the solid line in Figure 31. The characteristic curve of five-photon photoemission (dashed line) is given for comparison. Also calculated in [70] is the relationship between photocurrent and laser radiation frequency (Figure 34). The calculation was performed for a silver photocathode. Evidently the relationship between emission current and frequency is nonmonotonic. At high intensities, however, there occurs due to cathode heating a mixing of currents of different orders of magnitude, which lead to smoothing of the frequency relation of the total current.

As was already noted in Chapter 4, experiments [63] can serve as a qualitative confirmation of the described calculations; in these experiments an increase in the nonlinearity index in comparison with smooth pulses of the same intensity was observed for pulses with irregular structure. Since for irregular pulses instantaneous intensity values may significantly exceed the average pulse values, in this case it is natural to expect a more substantial cathode heating than in the case of a smooth pulse, which can become the cause of observed increase in nonlinearity.

The above interpretation, however, is not the only possible one. In [75] the author proposed a different version of explanation of the results in [63]. According to [75], the emission mechanism is in two stages: initially, as a result of light absorption, there occurs excitation of surface plasmons in the metal; subsequently interaction of plasmons with electrons leads to the occurrence of emission current. Since plasmon energy exceeds work function, the observed value of the nonlinearity index should be greater than n_0. Evidently additional experiments are needed, which would make it possible to judge more definitely the mechanism of occurrence of emission with abnormally high degrees of nonlinearity.

d) Analysis of Surface Photoeffect, Based on Theory of Threshold Phenomena

Of great significance for theory of nonlinear photoemission is substantiation and elucidation of the limits of applicability of the phenomenological approach, with the aid of which a large number of important results have been obtained. Important in particular is an answer to the question: to what degree are the results of a phenomenological examination connected with the features of a concrete model? A fairly complete answer to this question is contained in a series of studies by Brodskiy and Gurevich, contained in monograph [23]. In the case of linear photoeffect, the same question was examined in [66, 67], using different methods. Since exhaustive information on the status of this problem is contained in [23], we shall not go into detail but shall merely state the problem and list the principal results.

Electron photoemission is viewed [23] as inelastic scattering of a photon by a metal. A general analysis of such scattering can be performed without resorting to an examination of a concrete model of a scatterer, within the framework of so-called threshold approximation. The basic assumption behind threshold approximation is that electron final energy is assumed small in comparison with the energy of electron binding in the metal. In order to compute emission current it is necessary to find the wave functions of the final state. After separating the time factor, the coordinate part of these functions satisfies at a great distance $x>x_0$ from the surface Schroedinger equation

$$\left[\frac{d^2}{dx^2}+p^2-2V(x)\right]\psi=0.$$

In the case of n-photon emission

$$p^2 = 2E_j - p_{\parallel}^2, \quad E_j = E_i + n\omega.$$

Potential V(x) describes Coulomb interaction between emitted electron and surface $V(x)=(2\varepsilon x)^{-1}$, ε -- dielectric constant. With emission into an electrolyte, this interaction can be disregarded. On the basis of certain asymptotic solutions to the equation, one can calculate current at a great distance from the surface:

$$j(p) = p\,|\Lambda|^2 |C_0|^2, \quad C_0^2 = \frac{\mu}{\exp\mu - 1}, \quad \mu = -(4\varepsilon p)^{-1}$$

Factor $|\Lambda|^2$, entering the expression for j(p), is determined by the interaction of an electron with a light wave in the surface layer, where the potential gradient is large and cannot be found in the general form. If we adopt a model of free electrons in a square potential well V_0, in depth, for a one-photon surface effect calculation [14, 61] gives

$$|\Lambda^{(1)}|^2 = 2E_F \mathcal{E}_\perp^2/\omega^4.$$

For absorption of a large number of photons, there follows from perturbation theory an estimate of order of magnitude

$$|\Lambda^{(n)}|^2 \sim |\Lambda^{(1)}|^2 (\mathcal{E}_\perp^2/\omega^3)^{n-1}.$$

Utilizing this expression and averaging current by energy distribution of electrons, we obtain a formula for the current of n-photon emission (dimensional variables)

$$j_n = \frac{m(kT)^2}{2\pi^2\hbar^3} |\Lambda^{(n)}|^2 \sqrt{\frac{E_e}{E_F}} \int_0^\infty dx \left[1 - \exp\left(-\sqrt{\frac{\sigma}{x}}\right)\right]^{-1} \ln(1 + e^{\beta\sigma - x}),$$

where

$$\sigma = \frac{E_e}{kT}, \quad \beta = \frac{\hbar(n\omega - \omega_0)}{E_c},$$

$$E_e = \frac{\pi^2 e^4}{8\varepsilon^2\hbar^2} \quad \text{и} \quad \omega_0 = \frac{A}{\hbar}.$$

Within the limit of low temperatures for emission into a vacuum we obtain

$$n = \begin{cases} 0, & n\omega < \omega_0, \\ \dfrac{m}{4\pi^2\hbar^2} |\Lambda^{(n)}|^2 \sqrt{\dfrac{E_e}{E_F}} (n\omega - \omega_0)^2, & n\omega > \omega_0. \end{cases}$$

In the case of emission into a dielectric, the expression for current is determined by the value of parameter β. In the immediate vicinity of the threshold, when $\beta<<1$, the same result is obtained as for emission into a vacuum. For fairly large ε, however, case $\beta>>1$ may be realized, where image forces do not affect electron motion. In this case the result has the form

$$j_n = \frac{2m}{15\pi^2 h^{3/2}} E_F^{-1/2} |A^{(n)}|^2 (n\omega - \omega_0)^{5/2} \qquad (n\omega > \omega_0).$$

This formula received confirmation during investigation of photoemission into an electrolyte.

e) Remarks on Interior Nonlinear Photoeffect

Up to this point our discussion has applied primarily to surface photoeffect, whereby absorption of light is dictated by the potential gradient in the surface layer. Another cause of light absorption in metals is scattering of electrons on phonons and impurities in the interior. This mechanism is the cause of the interior photoeffect. Substantial physical differences between surface and interior photoeffect were indicated in a study by Tamm and Schubin [76].

Experimentally the character of absorption is usually established on the basis of the polarization relationship of photocurrent. Corresponding measurements for nonlinear photoemission, described in sections 2 and 4, indicate that for n=3, 5 photoemission is of a surficial character. At the same time the results obtained in [34] indicate that two-photon photoeffect on sodium is internal. Experiments [42-45] indicate the interior nature of two-photon emission into electrolyte. A substantial internal component is also characteristic of one-photon emission (see [37, 77]). Evidently one of the reasons for the absence of an internal component in photoemission with a sufficiently high degree of nonlinearity is that the thickness of the layer within the metal in which field intensity is sufficient to obtain an appreciable photocurrent, in the case of an n-quantum process is n times less than in the case of a single-quantum process.

In the linear case experimental data on interior photoeffect are well explained by the phenomenological theory of Spicer et al [37, 48, 49], which views emission as a sequence of three processes: optical excitation of electrons in the interior of a metal, movement of a portion of the excited electrons to the surface, and subsequent overcoming of the surface barrier. Scattering of electrons in the interior and their reflection from the surface are in the simplest case taken into account by introduction of an effective length of electron yield. In a number of studies (see, for example, [78, 79]) the movement of an excited electron to the surface is examined in greater detail with utilization of a random migration model.

An obvious shortcoming of theory [37] is separation of the emission event into individual stages, of which only the first is viewed as a quantum transition. The possibility of such a division is not obvious per se, which served as a basis for critique of the Spicer model in [80]. Comments on the limits of model applicability [37] can be found in article [81].

An attempt to use a three-stage model for constructing a theory of interior two-quantum photoeffect was undertaken in [34, 36]. The authors of these studies, however, did not perform a calculation of the probabilities of optical transitions in metal with absorption of two photons. And therefore the relations obtained in them cannot be directly compared with experimentation.

Matrix transition elements were calculated by Brodskiy and Tsarevskiy [81], who examined the problem of photoemission from an isolated center with spherically symmetrical potential and then generalized this result to a metal model in which wave functions within the metal are determined by the spherically symmetrical potentials of the ion cores in each cell. Without going into computation details (see [81]), we shall present the most significant results. It was noted above that the ratio of partial currents corresponding to absorption of n and n-1 photons when T=0 is equal in order of magnitude to perturbation theory parameter

$$\Delta/\hbar\omega \sim e^2 \mathcal{E}^2/m\hbar\omega^3.$$

In the case of interior photoeffect, the following estimate occurs for the j_2/j_1 ratio:

$$\frac{j_2}{j_1} \approx \frac{\Delta}{\hbar\omega}\left[(\hbar\omega)^{-1}\frac{m}{\hbar^2}\overline{\left(\frac{r^2\,\partial V(r)}{\partial r}\right)^2}\right],$$

where V(r) is the potential of the ion core, and the line above designates an average for the elementary cell. Usually the expression in square brackets is in the order of several tens, so that the relative probability of two-quantum interior photoeffect is considerably greater than that of surface photoeffect. This result is in agreement with experiments on emission into an electrolyte [43], where the ratio of two-photon and one-photon currents was directly measured. The relationship between interior photocurrent on the one hand and angles of incidence and polarization on the other is determined by the band structure of the metal. For a metal with an s-band, with light polarization in the plane of incidence (p-polarization), the angular dependence is given with formulas

$$j_{1p} \sim (\omega-\omega_0)^{\nu}\left[\sin^2\zeta + O\left(\frac{\omega-\omega_0}{\omega_0}\right)\right],$$

$$j_{2p} \sim (2\omega-\omega_0)^{\nu}\left[\sin^4\zeta + O\left(\frac{2\omega-\omega_0}{\omega_0}\right)\right],$$

where ζ is the angle of passage of light in the metal, connected with the angle of incidence by Fresnel formulas [19, 82], $\nu=2$ for emission into a vacuum and $\nu=5/2$ for emission into an electrolyte. For light polarized perpendicular to the plane of incidence (s-polarization), single-photon emission current is independent of angles. The above formulas apply to the threshold region of energies $|n\omega-\omega_0|<<\omega_0$. It follows from them that interior photocurrent should reveal just as pronounced a polarization dependence as surface photocurrent.

We shall further note that in accordance with [81], with normal incidence of light Fowler's square law for emission into a vacuum should change to a cubic law. The deviation from Fowler's law for photoemission from single crystals of copper observed in [83] can evidently be viewed as confirmation of this conclusion of theory.

For metals with complex band structure, in which the electron initial state corresponds to an orbital moment differing from zero, the angular dependence of a two-photon photocurrent with p-polarization of the incident wave is given with the relation

$$j_{2p} \sim (2\omega - \omega_0)^{\nu} (a \sin^4 \zeta + b \sin^2 \zeta \cos^2 \zeta + c \cos^4 \zeta),$$

where constants a, b and c can be of one order, so that in contrast to surface photoeffect, photocurrent with normal incidence of light can be compared with that measured with oblique incidence.

Thus existing theoretical models of nonlinear photoeffect provide a satisfactory qualitative explanation of experimental data. Very significant progress has been made in understanding photoeffect in strong optical fields. However, a number of fine details of the effect, in particular the relationship between emission current and frequency of light in a nonthreshold factor and the relationship of its angular and polarization dependences with band structure of the metal require further theoretical and experimental study. At the same time the achieved level of theory and experiment permit a quantitative description of the principal features of multiple-photon photoeffect.

In conclusion the authors should like to express their sincere gratitude to S. D. Babenko, Ya. Berg, A. M. Brodskiy, N. B. Delone, N. A. Inogamov, I. I. Kantorovich, N. Kroo and Z. Horvath for numerous useful discussions and assistance at various stages of the project.

Institute of Theoretical Physics imeni L. D. Landau of the USSR Academy of Sciences
Institute of Chemical Physics of the USSR Academy of Sciences, Chernogolovka (Moskovskaya Oblast)
Central Institute of Physical Research of the Hungarian Academy of Sciences, Budapest

BIBLIOGRAPHY

1. Delone, N. B. UFN, 115, 361 (1975).

2. Nuckolls, J. L.; Wood, L.; Thiessen, A.; and Zimmermann, G. NATURE, 239, 139 (1972).

3. Brueckner, K., and Jorna, S. REV. MOD. PHYS., 46, 325 (1974).

4. Prokhorov, A. M.: Anisimov, S. I.; and Pashinin, P. P. UFN, 119, 401 (1976).

5. Letokhov, V. S., and Mur, S. B. KVANT. ELEKTRON., 3, 122, 485 (1976).

6. Kazantsev, A. P. Author's Abstract of Doctoral Dissertation, Moscow, ITF AN SSSR, 1976.

7. Levinson, I. B. FTP 7, 1673 (1973).

8. Anisimov, S. I.; Imas, Ya. A.; Romanov, G. S.; and Khodyko, Yu. V. "Deystviye izucheniya bol'shoy moshchnosti na metally" [Effect of High-Power Radiation on Metals], Moscow, Nauka, 1970.

9. Barashev, P. P. PHYS. STAT. SOL., a9, 9 (1972).

10. Makinson, R. E. B., and Buckingham, M. J. PROF. PHYS. SOC., A64, 135 (1951).

11. Teich, M. S.; Schroeder, J. M.; and Wolga, G. J. PHYS. REV. LETT., 13, 611 (1964).

12. Farkas, Gy.; Naray, Z. S.; and Varga, P. PHYS. LETT., A24, 572 (1967).

13. Smith, R. L. PHYS. REV., 128, 2225 (1962).

14. Adawi, L. Ibid., A134, 788 (1964).

15. Bunkin, F. V., and Fedorov, M. V. ZhETF, 48, 1341 (1965).

16. Logothetis, E. M., and Hartman, P. L. PHYS. REV., 187, 460 (1969).

17. Gladun, A. D., and Barashev, P. P. UFN, 98, 493 (1969).

18. Farkas, Gy. In "Conference on Interaction of Electrons With Strong Electromagnetic Field. Invited Papers," Budapest, 1973, page 179.

19. Sokolov, A. V. "Opticheskiye svoystva metallov" [Optical Properties of Metals], Moscow, Fizmatgiz, 1961.

20. Bunkin, F. V., and Prokhorov, A. M., ZhETF, 52, 1610 (1967).

21. Anisimov, A. I.; Kapeliovich, B. L.; and Perel'man, T. L. ZhETF, 66, 776 (1974).

22. Anisimov, S. I.; Inogamov, N. A.; and Petrov, Yu. V. PHYS. LETT, A55, 449 (1976).

23. Brodskiy, A. M., and Gurevich, Yu. Ya. "Teoriya fotoemissii iz metallov" [Theory of Photoemission From Metals], Moscow, Nauka, 1973.

24. Silin, A. P. FTT, 12, 3553 (1970).

25. Panarella, E. LETT. NUOVO CIMENTO 3, 417 (1972).

26. Farkas, Gy.; Horvath, Z. Gy.; Kertesz, I.; and Kiss, G. Ibid., 1, 314 (1971).

27. Lichtman, D., and Ready, J. F. PHYS. REV. LETT., 10, 342 (1963).

28. Verber, C. M., and Adelman, A. M. J. APPL. PHYS., 36, 1522 (1965).

29. Honig, R. E., and Woolston, J. R. APPL. PHYS. LETT., 2, 138 (1963).

30. Redi, Dzh. "Deystviye moshchnogo lazernogo izlucheniya" [Effect of High-Power Laser Radiation], Moscow, Mir, 1974.

31. Ready, J. F. PHYS. REV., 137, 620 (1965).

32. Knecht, W. I. APPL. PHYS. LETT., 8, 253 (1966).

33. Marinchuk, M. E. PHYS. LETT, A34, 97, (1971).

34. Teich, M. C., and Wolga, G. J. PHYS. REV., 171, 809 (1968).

35. Teich, M. C., and Wolga, J. J. OPT. SOC. AM., 57, 542 (1967).

36. Bloch, P. J. APPL. PHYS., 35, 2052 (1964).

37. Smith, N., and Spicer, W. E. PHYS. REV., 188, 593 (1961).

38. Farkas, Gy.; Kertesz, I.; Naray, Zs.; and Varga, P. PHYS. LETT., A25, 527 (1967).

39. Logothetis, E. M., and Hartman, P. L. PHYS. REV. LETT., 18, 581 (1967).

40. Farkas, Gy.; Kertesz, I.; and Naray, Zs. PHYS. LETT., A28, 190 (1968).

41. Louis-Jacquet, M. C. R. AC. SCI., B273, 192 (1971).

42. Korshunov, L. I.; Benderskiy, V. A.; Gol'danskiy, V. I.: and Zolotovitskiy, Ya. M. PIS'MA ZhETF, 7, 55 (1968).

43. Babenko, S. D.; Benderskiy, V. A.; and Rudenko, T. S. Ibid., 17, 71, (1973).

44. Babenko, S. D.; Benderskiy, V. A.; Krivenko, A. G.; and Rudenko, T. S. FTT, 16, 1337 (1974).

45. Babenko, S. D.; Benderskii, V. A.; Krivenko, A. G.; Brodskii, A. M.; and Velichko, G. I. PHYS. STAT. SOL. (1976).

46. Barker, G. C.; Gardner, A. W.; and Bottura, G. J. ELECTROANAL. CHEM., 45, 21 (1973).

47. Benderskii, V. A.; Babenko, S. D.; Zolotovitskii, Ya. M.; Krivenko, A. G.; and Redenko, T. S. Ibid., 56, 325 (1974).

48. Berglund, C. N., and Spicer, W. E. PHYS. REV., 136, 1030 (1964).

49. Berglund, G. N., and Spicer, W. E. Ibid., page 1044.

50. Keldysh, L. V. ZhETF, 47, 1945 (1964).

51. Gontier, Y., and Rahman, N. K. NUOVO CIMENTO, 9, 537 (1974).

52. Geltman, S., and Teague, M. R. J. PHYS., B7, L22 (1974).

53. Mittleman, M. H. PHYS. LETT., A47, 55 (1974).

54. Brodskiy, A. M., and Gurevich, Yu. Ya. ZhETF, 60, 1452 (1971).

55. Basov, N. G.; Butslov, M. M.; et al. ZhETF, 65, 906 (1973).

56. Farkas, Gy., and Horvath, Z. Gy. "Lasern und ihre Anwendungen" [Lasers and Their Applications], Dresden, 1970.

57. Farkas, Gy.; Horvath, Z. Gy.; and Kertesz, I. LETT. NUOVO CIMENTO, 1, 1606 (1971).

58. Farkas, Gy.; Horvath, Z. Gy.; and Kertesz, I. PHYS. LETT., A39, 231 (1972).

59. Farkas, Gy., and Horvath, Z. GY. OPTICS COMM., 12, 392 (1974).

60. Farkas, Gy.; Lompre, L. A.; and Thebault, J. Saclay Preprint, D Ph, 75, 186 (1975).

61. Mitchell, K. PROC. ROY. SOC., A153, 513 (1936).

62. Baz', A. I.; Zel'dovich, Ya. B.; and Perelomov, A. M. "Rasseyaniye, reaktsii i paspady v nerelyativistskoy kvantovoy mekhanike" [Scattering, Reactions and Decays in Nonrelativistic Quantum Mechanics], Moscow, Nauka, 1971.

63. Farkas, Gy.; Horvath, Z. Gy.; Lompre, L. A.; and Petite, G. In "Second Conference on Interaction of Electrons With Strong Electromagnetic Field, Budapest, 6-10 October 1975," Abstract of Contributed Papers.

64. Anisimov, S. I.; Inogamov, N. A.; and Petrov, Yu. V. Ibid.

65. Fowler, R. H. PHYS. REV., 38, 45 (1931).

66. Schaich, W. L., and Ashcroft, N. W. Ibid., B3, 2452 (1971).

67. Mahan, G. PHYS. REV. LETT., 24, 1068 (1970).

68. Sutton, L. Ibid., page 386.

69. Marinchuk, M. Ye. IZV. AN MOLD. SSR, Physical and Mathematical Sciences Series, 12, 93 (1966).

70. Kantorovich, I. I. ZhTF, 47, 660 (1977).

71. Bete, G., and Zommerfel'd, A. "Elektronnaya teoriya metallov" [Electron Theory of Metals], Moscow-Leningrad, GTTI, 1933.

72. Perelomov, A. M., and Popov, V. S. ZhETF, 54, 1799 (1967).

73. Nikishov, A. I., and Ritus, V. I. ZhETF, 52, 223 (1967).

74. Kaganov, M. I.; Lifshits, I. M.; and Tanatarov, L. V. ZhETF, 31, 242 (1956).

75. Kroo, N. Cited in [63].

76. Tamm, I., and Schubin, S. ZS. PHYS., 68, 71 (1931).

77. Krolikowski, W. F. and Spicer, E. PHYS. REV., B1, 478 (1970).

78. Kane, E. O. Ibid., 147, 335 (1966).

79. Duckett, S. W. Ibid., 166, 302 (1968).

80. Mahan, G. D. Ibid., B2, 4334 (1970).

81. Brodskiy, A. M., and Tsarevskiy, A. V. ZhETF, 69, 936 (1975).

82. Born, M., and Vol'f, E. "Osnovy optiki" [Fundamentals of Optics], Moscow, Nauka, 1970.

83. Gartland, P. O.; Berge, S.; and Slagswold, B. PHYS. REV. LETT., 30, 916 (1973).

TABLE OF CONTENTS

3024
CSO: 8044/ 0379

SCIENTISTS AND SCIENTIFIC ORGANIZATIONS

UDC 061.3 (47+57)

CONFERENCE ON NATURAL PLANT RESOURCES HELD IN TASHKENT

Leningrad RASTITEL'NYYE RESURSY in Russian No 4, 1977 received 20 Jun 77 pp 715-721

/Report on conference by D. K. Saidov, K. Z. Zakirov, P. D. Sokolov, L. P. Markova, L. I. Medvedeva and L. Ye. Pauzner, Institute of Botany of the Uzbek SSR Academy of Sciences, Tashkent, and Botanical Institute imeni V. L. Komarov of the USSR Academy of Sciences, Leningrad: "Conference on 'The Present Status of and Prospects for the Study and Use of the Natural Plant Resources of the USSR' (Tashkent 18-20 Apr 77)"/

/Text/ A conference on "The Present Status of and Prospects for the Study and Use of the Natural Plant Resources of the USSR" was held in Tashkent on 18-20 April 1977. This was a scientific coordination conference held within the framework of the annual session of the scientific council for the problem "The Biological Basis for a Rational Use, Transformation and Protection of the Plant World" of the USSR Academy of Sciences. The conference was organized by the above-mentioned scientific council of the USSR Academy of Sciences and the scientific council for the same problem of the Uzbek SSR Academy of Sciences, as well as the Botanical Institute imeni V. L. Komarov of the USSR Academy of Sciences (BIN) and the Institute of Botany of the Uzbek SSR Academy of Sciences. The holding of the conference on plant resources was coordinated with the State Committee for Science and Technology of the USSR Council of Ministers.

The conference had the following objects: 1) to sum up the study of plant resources in the Union republics and individual regions of the RSFSR during the Ninth Five-Year Plan and to determine the basic trends in scientific research in the field of the natural plant resources of the USSR for the next decade; 2) to disclose the needs of the national economy for raw plant materials obtained from wild-growing plants and to determine the extent to which they are met; 3) to clarify the situation with regard to the procurement of raw materials of wild-growing useful plants and to map out the measures for their improvement; 4) to discuss the measures for an increase in the efficiency of exploitation of natural plant resources and an accelerated introduction of results into the national economy; 5) to determine the possibilities of improving the coordination of research on plant resources.

About 60 people representing the main botanical institutions of the USSR Academy of Sciences, its departments, affiliates and scientific centers, academies of sciences of all the Union republics (with the exception of the Latvian SSR Academy of Sciences), and a number of all-union scientific research institutes of other departments, as well as certain Union ministries, all-union scientific production associations and organizations engaged in the procurement of raw materials of wild-growing useful plants, took part in the work of this conference.

The report by Al. A. Fedorov, corresponding member of the USSR Academy of Sciences, and P. D. Sokolov (BIN of the USSR Academy of Sciences, Leningrad) on the subject "The Present State of and Prospects for the Study and Use of the Plant Resources of the Natural Flora of the USSR" was heard at the general plenary meeting that opened the annual session of the scientific council for this problem of the USSR Academy of Sciences on 18 April. The report presented an analysis of the present state of the study and use of the wild-growing useful plants of USSR flora. It showed that discovering new useful plants and drawing them into the sphere of practical activity are part of the general task set by the 25th Party Congress for the study and rational use of the country's natural resources. The botanical institutions of the USSR Academy of Sciences and of the academies of sciences of the Union republics, the botanical departments of many universities and pedagogical, agricultural, medical and pharmaceutical higher educational institutions and many scientific research institutes of various departments engage in the study of the useful properties of plants of the natural flora of the USSR. Principal attention is given to medicinal, fodder and food plants.

Despite the wide scope of research, the useful properties of the plants of USSR flora have not yet been studied sufficiently. A rational use of already known plants has not been organized, some of them are procured on a scale threatening a complete destruction of a species (for example, many medicinal plants) and the reserves of other plants are consumed in negligibly small amounts (wild berries, fruits, nuts and mushrooms). The report noted the insufficient attention given in resources management investigations to the theoretical problems of botanical resources management and to the elaboration of methodological problems and possibilities for an overall and rational use of the wild-growing useful plants of USSR flora.

The first meeting of the conference was held in the evening of 18 April. K. Z. Zakirov, chairman of the scientific council for this problem of the Uzbek SSR Academy of Sciences, academician of the Uzbek SSR Academy of Sciences, opened it. In his introductory remarks he noted the great practical and scientific importance of the convened conference and expressed confidence in its successful work.

A. P. Tarasova (Moscow), representative of the USSR Ministry of Light Industry, presented a report entitled "The Present State of and Prospects for the Use of Raw Plant Materials by Light Industry Enterprises." Having noted that

ensuring the output of high-quality consumer goods is the main task of light industry during the Tenth Five-Year Plan, the speaker dwelled on the situation with respect to the use of raw plant materials for the tan extract industry. Despite the large reserves of raw tanning materials (spruce and larch bark), they are not procured to a sufficient degree and cannot meet the needs of tan extract production. The speaker pointed out a number of measures contributing to an increase in the procurements made and to an improvement in the quality of tan extracts.

In the report "The Present State of and Prospects for the Procurements of Raw Materials of Wild-Growing Plants (Berries, Fruits, Mushrooms, Nuts and Medicinal and Industrial Plants) in the System of Consumer Cooperatives" A. D. Agafonov (Moscow), chief of Tsentrkooplektekhsyr'ye of the USSR Tsentrosoyuz, showed the great importance of this system as one of the main procurement organizations in the country. A number of measures increasing the efficiency of procurement work have been implemented in the last few years. Technical retooling, personnel training and forms of work have been improved. However, the existence of a large number of organizations engaged in the procurement of wild-growing raw plant materials, the absence of unified procurement prices, difficulties with the provision of motor transport and insufficiently rational procurement methods--all this hampers a fundamental improvement in the business of procurements and their execution by the most efficient methods. The speaker recommended a number of measures to eliminate the existing shortcomings.

The report by O. L. Savel'yev (All-Union Soyuzlekrasprom Association of the USSR Ministry of Medical Industry, Moscow) presented a description of the present state of the procurements of medicinal raw plant materials and outlined the tasks of improving the needs of public health for medicinal plants. The speaker noted that the preparations made from medicinal plants comprise about 40 percent of the drugs used by Soviet medicine. Many organizations are engaged in the procurement of medicinal raw materials, but the needs of public health for the raw materials of many types of medicinal plants are not met fully. A set of measures contributing to an improvement in this situation have been implemented, but there are still a number of serious reasons hampering the procurement and delivery of medicinal raw materials. The speaker reported on the establishment under the All-Union Soyuzlekrasprom Association of the Interdepartmental Council for the Study, Use and Protection of the Resources of Wild-Growing Medicinal Plants and thoroughly discussed its basic tasks and functions. The All-Union Scientific Research Institute of Medicinal Plants (VILR) provides scientific and methodological advice on the problems examined by the council. In 1978 the council is to hold an all-Union scientific and technical conference on problems connected with the uncovering, rational use and protection of the resources of wild-growing medicinal plants. The speaker made a number of proposals for their inclusion in the resolution of this conference.

In the report "The Present State of and Prospects for the Study and Use of Wild-Growing Medicinal Plants" P. S. Chikov (VILR, Moscow Oblast) discussed the main trends in and results of the research conducted by VILR, enumerated the most valuable preparations developed in this institute and manufactured by the chemical and pharmaceutical industry and gave a brief description of the present state of the production and procurement of medicinal raw materials. At present 26 specialized sovkhozes of the All-Union Soyuzlekrasprom Association cultivate 56 medicinal crops. However, the raw materials of a large number of medicinal plants are procured in nature. The speaker discussed in detail the following possible ways of eliminating the shortage of raw materials of scarce wild-growing medicinal plants: uncovering productive thickets and developing methods of increasing their productivity, establishing reserved forests, expanding the existing plantations of individual species and introducing the species of the scarcest medicinal plants into cultivation. The speaker also dwelled on the shortcomings in the research on medicinal plants connected with the absence of an interdepartmental coordinating body until recently.

A report on the subject "The Prospects for the Development of the Licorice Sector on the Basis of an Improvement in Natural Thickets and Establishment of Cultivated Plantations" was made by L. A. Varganov (All-Union Soyuzlakritsa Association of the USSR Ministry of Agriculture, Chardzhou). The speaker discussed the main trends in the use of the licorice root and raised the question of the need for a fuller utilization of raw licorice materials, in particular, the above-ground mass and oil seed meal. The considerable reduction in licorice thickets owing to the intensive exploitation requires the implementation of a number of necessary measures for preserving and improving them, for example, turning the most productive licorice associations into reservations, establishing cultivated plantations and so forth. The All-Union Soyuzlakritsa Association enlisted a large group of experts in resources from the institutes of botany of the academies of sciences of Turkmenia, Uzbekistan, Kazakhstan and other institutions. For an approval of the results obtained it is necessary to establish in the system of the All-Union Soyuzlakritsa Association pilot stations in the main regions of location of licorice thickets. The territorial agroindustrial complexes located in some oblasts of the Central Asian republics and Kazakhstan are the best form of organization of licorice farms.

The present state of and prospects for the use of the nontimber output of forests were set forth in a report with such a title by V. M. Zubarev (All-Union Scientific Research Institute of Silviculture and Forestry Mechanization, Moscow Oblast). The speaker discussed the present state of procurements of the nontimber output of forests (berries, mushrooms, nuts and medicinal raw materials) made in the system of the USSR State Committe for Forestry and also dwelled on the basic results of the scientific research conducted in institutes of timber specialization. As a result of the introduction of a number of recommendations it was possible to improve the planning of procurements and to increase their efficiency. However, there are still many

unsolved problems and organizational shortcomings in the exploitation of the nontimber output of forests (lack of valuable data on the resources of this output, harvest forecasting methods and so forth). The speaker noted the advisability of establishing a production association (of the "Les" /Forest/ type of association in the Polish People's Republic) and made proposals for an improvement in work in the field of study and use of the nontimber output of forests.

The reports by S. I. Kozenko "The Use of Raw Plant Materials in the Canning Industry" (All-Union Scientific Research Institute of the Canning Industry, Moscow Oblast) and by L. K. Pozdnyakov "The Present State of and Prospects for the Development of Forest Resources Management" (Institute of Forestry and Timber of the Siberian Department of the USSR Academy of Sciences, Krasnoyarsk) were not presented owing to the speakers' absence.

The report by A. I. Arinshteyn, N. I. Radchenko and A. A. Serkova "The Present State of and Prospects for the Study and Use of Wild-Growing Essential Oil Plants for the Next Decade" (Scientific Production Association for Essential Oil and Essential Oil Crops of the USSR Ministry of Agriculture, Simferopol') was read by N. M. Serbina at the morning meeting on 19 April. The report noted that the domestic perfumery and cosmetics industry uses the raw materials of isolated wild-growing species, although the investigations conducted revealed many promising species of essential oil plants. The exploitation of the reserves of the latter presents some difficulties. The introduction of a number of valuable species into cultivation is the basic way of increasing the assortment of essential oil raw materials. An organization of plant sovkhozes in the country's various zones is necessary. It is necessary to expand the search for new sources of essential oil raw materials, as well as to intensify the research on their overall use.

The second day of the conference work--19 April--was devoted to reports by the representatives of the botanical institutions of the republic academies of sciences, as well as affiliates, departments and scientific centers of the USSR Academy of Sciences, under the general title "The Present State of and Prospects for the Study of Plant Resources."

The morning meeting was opened with a report by K. Z. Zakirov, academician of the Uzbek SSR Academy of Sciences (Institute of Botany of the Uzbek SSR Academy of Sciences). He discussed the main trends in the work of the division of raw plant materials of the Institute of Botany of the Uzbek SSR Academy of Sciences and its five laboratories, where tannin, glycyrrhizin containing, saponin bearing, essential oil, dye yielding and medicinal plants are studied. The investigations envisage the determination of the reserves of these plants and the possibilities of introducing them into cultivation. The investigation of Spanish licorice occupies an important place. Plantations have been established and its characteristics as an improver of saline soil are studied. On the basis of the division's recommendations some aromatic plants are used in the production of nonalcoholic beverages. Methods of using anthocyans from Asia poppy and hollyhock petals as food dyes have

been developed. The speaker made a number of proposals for an accelerated introduction of research results, as well as for the development of a system of scientifically substantiated measures for the protection and reproduction of valuable species of useful plants.

M. K. Kukenov (Institute of Botany of the Kazakh SSR Academy of Sciences, Alma-Ata) reported on the large-scale and all-around investigations of individual groups of useful plants of Kazakhstan flora. Monographs and thematic collections on tannin, medicinal and some other useful plants were published and practical recommendations for a rational use of these plants were developed. A search for and detection of valuable medicinal and essential oil plants in the flora of East Kazakhstan are the basic trends. These investigations are also conducted in Kazakhstan State University in the department of chemistry of natural compounds and in the laboratory of biochemistry of plants of the Institute of Botany. The following are the primary tasks: mapping and specifying the reserves of raw plant materials and establishing specialized farms for the cultivation of species whose natural reserves are limited. The speaker noted that personnel training is not carried out efficiently in Kazakhstan. A course in botanical resources management is given in only a few higher educational institutions. Research coordination must also be intensified. Regular conferences on plant resources must be held (once in 4 years) and information on holding all-Union and regional conferences must be improved.

The report by B. B. Kerbabayev (Institute of Botany of the Turkmen SSR Academy of Sciences, Ashkhabad) stressed that, despite the small collective of the division for plant resources, extensive work on the study of licorice was done. Licorice reserves in the republic were reduced considerably. Therefore, a number of measures making it possible to restore licorice thickets over a period of 2 years were developed. However, the introduction of licorice into production cultivation is the basic path. A study of the useful plants of Kopet-Dag is the second trend in work. A total of 34 species of raw material plants were detected and the regions of their procurement and methods of rational use were determined.

I. G. Chukavin (Institute of Botany of the Tadzhik SSR Academy of Sciences, Dushanbe) dwelled on the study of medicinal plants in the republic. This work is done in a number of institutes (Leninabad Pedagogical Institute, Institute of Gastroenterology and Institute of Chemistry of the Tadzhik SSR Academy of Sciences). Large amounts of raw materials of species of ephedra, sea buckthorn, Spanish licorice and Victor ungerniya are procured on the republic's territory. Therefore, it was necessary to study their reserves, as well as those of some other official medicinal plants. Research on the development of measures for a rational use and protection of ephedra, Turkestan adonis and ungerniya is planned. A coordinating council for the study of medicinal plants under the chairmanship of Kh. Kh. Mansurov, corresponding member of the Tadzhik SSR Academy of Sciences, was established in the republic.

The report by Z. S. Arbayeva (Institute of Biology of the Kirgiz SSR Academy of Sciences, Frunze) noted that a number of the republic's institutes and the Botanical Garden of the Kirgiz SSR Academy of Sciences are engaged in the study of plant resources. As a result, more than 4,000 species of plants of varying economic importance were detected, but only a small part was studied. Horsetail ephedra, fetid meadowrue, lanceolate thermopsis, Spanish licorice, sea buckthorn and many other medicinal plants are procured in the republic, although the reserves of some of them have been exhausted completely. There are no reliable maps for the location of the thickets of these species, or recommendations for their rational use. A laboratory for plant resources was organized in the Institute of Biology of the Kirgiz SSR Academy of Sciences in 1976. A planned and comprehensive study of raw material plants and the development of methods of using them efficiently are the basic tasks of this laboratory.

N. M. Ismailov (Institute of Botany of the Azerbaydzhan SSR Academy of Sciences, Baku) dwelled on the results of the work done by the division for plant resources as of 1970. Large-scale research on the determination of the chemical composition of larkspur and nightshade species was conducted. Valuable sources of substances of curare- and cortisone-like effect were singled out. Kusary hollyhock as a source of polysaccharides and species of giant fennel as sources of coumarins were investigated in cooperation with BIN of the USSR Academy of Sciences. Much attention is given to spicy-aromatic and dye yielding plants and certificates of invention for the use of some of them in the food industry have been obtained. Dog rose species with a high vitamin content were detected and their reserves were established. The search for sources of biologically active substances of a varying therapeutic effect, as well as valuable dyes, especially for the food industry, is to be intensified and expanded in the next 15 years. Along with this special attention will be given to the study of the reserves of medicinal, dye yielding, spicy-aromatic and food plants and to problems of their rational use.

R. I. Gagnidze (Institute of Botany of the Georgian SSR Academy of Sciences, Tbilisi) discussed the resources management work carried out in a number of institutes of the Georgian SSR Academy of Sciences, as well as in sectorial institutes. In the last few years the Institute of Botany of the Georgian SSR Academy of Sciences has given much attention to the elaboration of problems connected with a rational use and improvement of natural fodder land, as well as to the study of wild-growing fruit plants. Biological-agronomical investigations of wild-growing useful plants are conducted. Extensive work on the search for biologically active substances, study of their chemical composition and establishment of pharmacological activity are conducted in the Institute of Pharmaceutical Chemistry of the Georgian SSR Academy of Sciences. More than 60 medicinal preparations from raw plant materials were developed. However, the reserves of many medicinal plants in the republic are very limited. It is extremely necessary to establish on Georgia's territory specialized sovkhozes for the cultivation of valuable medicinal plants. For a more efficient study of Georgia's medicinal flora and intensification of the coordination of this work, it is advisable to draw up a general plan of research conducted in the republic.

The report by K. M. Sytnik, academician of the Ukrainian SSR Academy of Sciences, and V. K. Myakushko (Institute of Botany of the Ukrainian SSR Academy of Sciences, Kiev) was devoted to the results of research on Ukraine's natural plant resources. A number of botanical institutions of the Ukrainian SSR Academy of Sciences, as well as botanical departments of universities and pedagogical and agricultural higher educational institutions, are engaged in the study of useful plants within the framework of the regional scientific council for this problems. Significant work is done on the study of medicinal plants (search for valuable species, determination of reserves, development of methods of cultivation and so forth), investigation of ecological-biological characteristics and recording of the reserves of berry bushes. The speakers noted that, as a result of inefficient procurements, the reserves of a number of species of medicinal plants are reduced and many of these plants must be included in the "red book." The speakers discussed the program of work on the study and rational use of medicinal plants developed for the Ukrainian SSR and spoke of the advisability of developing an all-Union program with the enlistment of a number of medical and other institutions in its execution. BIN of the USSR Academy of Sciences should provide general guidance for such a program. In the speakers' opinion, it is necessary to organize specialized farms for the cultivation of useful plants in the Union republics and to ask the appropriate departments to finance these operations.

The report by I. D. Yurkevich, academician of the Belorussian SSR Academy of Sciences, V. I. Parfenov, Ye. A. Sidorovich and M. A. Kudinov (Institute of Experimental Botany of the Belorussian SSR Academy of Sciences and the Central Botanical Garden of the Belorussian SSR Academy of Sciences, Minsk) was devoted to the results of the large-scale work done by Belorussian botanists on the study of the republic's plant resources. Investigations of the anthropogenic effect on the dynamics of the plant cover were conducted. The study of meadows and grass swamps in Poles'ye with an evaluation of their productivity was completed. On the basis of a contract with the Main Pharmaceutical Administration of the Belorussian SSR Ministry of Health the reserves of the basic medicinal plants procured on Belorussia's territory were determined and on this basis a long-term plan for the procurements of medicinal raw materials for the Tenth Five-Year Plan was prepared. Introduction work is one of the most important sections. Production tests of new silage plants (Veyrikh knotweed and Sosnovskiy cowparsnip) are conducted. The possibility of growing large cranberries and Spanish licorice was shown. Valuable decorative plants are introduced into cultivation. The main difficulties are connected with the process of introduction of research results into the national economy. Nor is there the proper coordination of work. The speakers proposed that work be done on plant resources according to a general plan for a number of Union republics, or on an all-Union scale with a subdivision of work throughout regions.

The report by M. V. Bodrug (Botanical Garden of the Moldavian SSR Academy of Sciences) noted that, in addition to the Botanical Garden, the Institute of Chemistry of the Moldavian SSR Academy of Sciences, Kishinev University and the Medical Institute are engaged in the study of plant resources

in the republic. Many valuable useful plants, especially essential oil, spicy-aromatic and medicinal, were detected. All the investigations are connected with the needs of the local industry--perfumery and wine industries. Large-scale introduction work has been done, because the reserves of wild-growing useful plants in Moldavia are very negligible. Subsequently, it is necessary to generalize the results of the work done in Moldavia on essential oil and spicy-aromatic plants in the appropriate compendiums and monographs.

The report by V. I. Marchyulenis (Institute of Botany of the Lithuanian SSR Academy of Sciences, Vil'nyus) was devoted to the results of scientific research on Lithuania's plant resources. A number of the republic's scientific institutions participate in this work. Principal attention is given to medicinal, industrial, fodder and food plants. A sharp reduction in the reserves of berry plants was established. It is necessary to organize reserved forests, as well as to implement a number of measures to increase the productivity of natural small fruit patches and to establish cultivated plantations. Introduction work with tannin and medicinal plants is carried out. It is absolutely necessary to establish specialized farms working with one or two crops, but executing this work on an agronomical level with the use of mechanization. The speaker proposed that the third scientific conference on the investigation and enrichment of the plant resources of the Baltic Republics and Belorussia be convened.

L. R. Laasimer (Institute of Zoology and Botany of the Estonian SSR Academy of Sciences, Tartu) reported that the work on the study of plant resources in Estonia is only beginning and is still of a random nature. In the republic there are reserves of mushrooms, berries and medicinal plants, but they are not fully used, because no one has studied them. Therefore, it is necessary to establish a central laboratory for plant resources under the Estonian SSR Academy of Sciences, whose main task would be the development of the scientific basis for the procurement and cultivation of useful plants, search for new effective medicinal plants and coordination of this work in the republic.

In her report K. A. Sobolevskaya (Central Siberian Botanical Garden of the Siberian Department of the USSR Academy of Sciences (TsSBS), Novosibirsk) dwelled on the basic trends in the research on plant resources conducted in Siberia. They are primarily detecting promising useful species, determining and mapping their reserves and introducing the most valuable of them. Essential oil, spicy-aromatic, tannin and medicinal plants are studied. All these groups find application in the local industry. Valuable tanning agents and spicy-aromatic plants were detected. Important problems will have to be solved in the next decade. Plans are made to publish the two-volume compendium "Rastitel'nyye Resursy Sibiri" /Siberia's Plant Resources/ and books on the plant resources of individual regions of the Baykal-Amur Trunk Line. The speaker made a proposal on the elimination of departmental limits in the coordination of work on plant resources.

In their report A. F. Zhuravkov and V. N. Dyukarev (Botanical Garden of the Far Eastern Scientific Center of the USSR Academy of Sciences, Vladivostok) noted that extensive work on the detection and study of valuable medicinal, essential oil, fodder, decorative and food plants was done in the region. The region's flora is the source of valuable wood species and of the nontimber output of forests. However, the procurements of valuable medicinal plants, raw materials of the Amur cork tree, food plants and timber are made without taking the reserves and possibilities of reproducing them into account. At present the degree of study of plant resources varies in different regions. The resources of the northern regions have not yet been studied sufficiently. In the region there is no efficient coordination of the research conducted. It is necessary to intensify the overall study of promising medicinal and food plants and to expand the work on the introduction of disappearing useful plants.

The evening meeting on 19 April began with a report by Ye. V. Kucherov (Institute of Biology of the Bashkir Affiliate of the USSR Academy of Sciences, Ufa). The speaker dwelled on the results of the study of plant resources in South Urals. The flora of this region has more than 450 species of useful plants, which can be the objects of procurements. However, raw materials of only 120 species are procured. Reserves of medicinal plants have been detected, extensive work is done on the study of fodder and honey plants, but so far tanning plants have been studied very inefficiently. The publication of the book "Resursy Lekarstvennykh Rasteniy Bashkirii" /Resources of Bashkiria's Medicinal Plants/ is planned for the next 5-year period. A commission for the coordination of scientific research on plant resources in South Urals was established in 1971. A regular conference on the region's plant resources will be held in Sverdlovsk in 1978.

The report by A. I. Mikhkiyev (Presidium of the Karelian Affiliate of the USSR Academy of Sciences, Petrozavodsk) discussed the results of the study of Karelia's plant resources conducted in three basic directions, that is, study of fodder plants, useful plants inhabiting swamps and water logged land and nontimber plant resources (berry and medicinal plants). The biological reserves of some species in the republic's southern part were determined, which made it possible to increase the procurements of their raw materials. Swamps with industrial reserves of berries and medicinal raw materials were recorded, as a result of which 40 swamp areas were declared reserved areas. Much attention was given to the methodological problems of determining and mapping reserves. The ecological-biological characteristics of a number of species are also studied and experiments on small cranberry cultivation have been set up. The speaker enumerated the basic tasks connected with this work for the next few years.

The report by A. V. Polozhiy and T. A. Revina (Tomsk State University) on the subject "Siberian Species of the Genus Rodiola as the Source of Physiologically Active Substances and Their Introduction Into Cultivation" was heard at the conclusion of the evening meeting. The investigations of the

golden root are conducted by the botanists, pharmacologists and phytochemists of Tomsk and the introducers of TsSBS of the Siberian Department of the USSR Academy of Sciences. A detailed study of five species was made, their reserves were mapped and the possibilities for their procurements and prospects for cultivation were determined. A program of work on the study of useful plants (medicinal and food plants) in South Siberia for the Tenth Five-Year Plan was developed. The speaker made a number of proposals: on intensifying the coordination in the field of botanical resources management; on the need to develop resources management terminology; on improving the training of experts in resources management and specialists in the protection of the plant world.

The following spoke during the debate on the reports: L. K. Klyshev (Institute of Botany of the Kazakh SSR Academy of Sciences, Alma-Ata), who proposed that the problem of the possibility of using the reserves of tannin plants in Kazakhstan, as well as anabasis for agricultural needs, be examined; K. T. Tayzhanov (Institute of Chemistry of Plant Substances of the Uzbek SSR Academy of Sciences, Tashkent), who discussed the work done in the institute on the search for and study of some medicinal plants, and K. Z. Zakirov (Institute of Botany of the Uzbek SSR Academy of Sciences), who made a number of specific proposals for the protection of valuable medicinal plants.

Reports examining some theoretical and methodological problems of botanical resources management were read at the morning meeting on 20 April. The report by Al. A. Fedorov, corresponding member of the USSR Academy of Sciences, and M. G. Pimenov "Chemosystematics as a Method of Botanical Resources Management" (BIN of the USSR Academy of Sciences, Moscow State University) was heard with great interest. The report gave a serious substantiation of the need for the further expansion of the use in botanical resources management of the chemosystematic method based on the knowledge of the correlation between the chemical composition and morphological characteristics of plants occurring in the process of evolution. The speakers stressed that chemosystematic investigations conducted simultaneously with a taxonomic revision are the most productive. It is very important to observe the requirements for an accurate documentation of herbarial material. Using a number of examples, the speakers showed how neglect of this depreciated the results of chemosystematic and phytochemical investigations. The importance of intraspecific chemical variability for purposes of botanical resources management was also noted.

The report by M. Ye. Pimenova "Methods of Recording the Reserves of Raw Plant Materials in Mountain Regions" (VILR) presented an in-depth scientific analysis of the specific characteristics of recording the reserve of the raw materials of plants in mountain habitats and showed in detail the need for using in this work statistical data processing methods, as well as various cartographic sources.

D. K. Budryunene (Lithuanian Scientific Research Institute of Forestry of the USSR Ministry of Forestry) presented a report on the subject "Problems of Economic Evaluation of Plant Resources." The speaker convincingly showed that the optimization of the use of natural plant resources is possible only on the basis of their economic evaluation, which includes a system of different evaluations depending on the purpose and type of the work done. This also determines the nature of the used methods. The speaker noted the insufficient study of the problems of economic evaluation of some types of plant resources and familiarized the participants with the methods of this evaluation of nontimber forest resources developed in the Lithuanian SSR. The main trends in work, whose development is necessary for an economic substantiation of the optimal use of natural plant resources, were enumerated.

The tasks of the investigation and methods of the evaluation of plant resources in the developed territories were the subject of the report by L. N. Il'ina (Institute of Geography of Siberia and the Far East of the Siberian Department of the USSR Academy of Sciences, Irkutsk). The speaker dwelled in detail on the overall program for the investigation of large economic regions developed by the division for economic evaluation of natural resources of the Institute of Geography of Siberia and the Far East and approved in the regions of West Siberia in 1971-1974. A study of the resources of the natural flora of the territory gravitating toward the Baykal-Amur Trunk Line has been conducted according to this program as of 1975. It is advisable to conduct resources management investigations according to this program in Yakutskaya ASSR and Krasnoyarskiy Kray. The speaker proposed that an "Atlas of Nontimber Plant Resources in Siberia" be prepared on the basis of a series of regional evaluation maps of useful plants.

The report by Ye. V. Kucherov ("Problems of Rational Use and Protection of Useful Plants" (Institute of Biology of the Bashkir Affiliate of the USSR Academy of Sciences, Ufa) presented a detailed analysis of the state of research on the protection and rational use of the resources of individual economically important groups of useful plants. This work was most seriously organized in connection with medicinal plants and is coordinated by a special interdepartmental commission on the study of wild-growing small fruit patches at the section for forestry management and dendrology of the All-Union Botanical Society. The publication of the "red book" of species of USSR flora, as well as a number of regional floras (Lithuanian SSR, Estonian SSR and so forth) is of great importance. The speaker stressed that the efforts of botanists who are experts in resources management should be directed toward the development of a set of measures contributing to the conservation of natural plant resources.

The report by A. K. Skvortsov and N. V. Trulevich "The Results of and Prospects for the Introduction of Plants of the Natural Flora of the USSR" (Main Botanical Garden of the USSR Academy of Sciences, Moscow) examined the main trends in and the results of work on the introduction of a number of species of useful plants conducted in the Main Botanical Garden of the USSR Academy of Sciences.

A. M. Chernyayeva (Sakhalin Comprehensive Scientific Research Institute of the Far Eastern Scientific Center of the USSR Academy of Sciences, Novo-Aleksandrovsk) presented information on the resources management work done in Sakhalin. T. B. Bulatova discussed the study of medicinal plants at the department of pharmacognosy of the Tashkent Medical Institute.

L. P. Markova, scientific secretary of the section for plant resources of the scientific council for this problem of the USSR Academy of Sciences (BIN of the USSR Academy of Sciences), read the draft resolution of the conference.

Those who spoke during the debate and the discussion of the resolution made proposals on improving coordination and noted the need for generalizing the data on individual trends in the problem (methods of determining reserves, plant resources of individual regions and so forth) and the advisability of establishing an information and bibliographical center, where all the literature on plant resources would be concentrated, and also made additions to the draft resolution. The proposed draft resolution was unanimously adopted by the participants in the conference.

Closing the conference, P. D. Sokolov, deputy chairman of the section for plant resources of the scientific council for this problem of the USSR Academy of Sciences (BIN of the USSR Academy of Sciences), noted the large volume of the valuable and new information obtained from the reports of the representatives of production organizations and all-Union scientific research sectorial institutes, as well as from the reports by the representatives of republic and regional centers for the study of plant resources, which the institutes of botany of the Union republics and the botanical institutions in the affiliates and departments of the USSR Academy of Sciences are. On behalf of the participants in the conference P. D. Sokolov thanked the collective of the Institute of Botany of the Uzbek SSR Academy of Sciences headed by its director, D. K. Saidov, academician of the Uzbek SSR Academy of Sciences, and also K. Z. Zakirov, chairman of the regional scientific council for the problem, academician of the Uzbek SSR Academy of Sciences, for the good organization of the conference and for the warm and cordial welcome to its participants.

The conference in Tashkent, which was held during the year of celebration of the 60th anniversary of the October Revolution, clearly showed the vast scale of the investigations of natural plant resources in the first socialist state in the world.

11,439
CSO: 1870

END